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INVESTIGATIONS ON THE STANDARDIZATION OF CITRUS TREES BY PROPAGATION METHODS

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INVESTIGATIONS

ON THE

STANDARDIZATION OF CITRUS TREES

BY

PROPAGATION METHODS

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FOREWORD.

We had hoped to be able to launch this publication with the aid of a blessing in the shape of a critical foreword by some recognized Citrus authority within the Empire. However, unavoidable delays have occurred during the final stages of its preparation, as for instance the arrival at the last moment of much pertinent new data and new references, all of which had to be incorporated, while there were received also a number of enquiries pressing to be answered on this very question of citrus standardization. These circumstances and the fact that the most optimistic calculations could not reduce the necessary postal delay to less than two months have unfortunately conspired to frustrate our design.

Although we have endeavoured to view the subject from every aspect, we are conscious that certain problems, with which we are only too familiar from their constant intervention in other branches of fruit research, may have been emphasized, while questions perplexing the citrus worker in other directions may have, perhaps, been less adequately dealt with. If this is so, we shall welcome criticism, since thus only can the difficulties besetting the individual worker be made known and the mutual exchange of ideas, which it is one of the duties of the Bureau to foster, be increased.

That the primary consideration of all Horticultural Research Workers must be the attainment of a knowledge of the standardization and potentialities of their experimental material was maintained by this Bureau when it first outlined its activities, and a promise was made to review, in due course, the progress so far made along those lines in one or more technical communications.

The amount of work that is actually under way with regard to the propagation and standardization of Citrus, the eminence of the workers in this field and the number of enquiries received by the Bureau on these particular points decided us to deal first with Citrus, particularly since so much is already available with regard to deciduous fruit plants.

That the standardization of Citrus material and a knowledge of the inherent behaviour of individual plants is at least as important as in the case of deciduous plants seems certain. But whilst methods of investigation may for a considerable period follow along the same general lines in both cases, there may in the end be quite a different solution for each. For instance, the now widely recognized phenomenon of polyembryony and the persistent and striking bud mutations in established—and probably also in quite young—Citrus plants, raise a whole set of problems which, in dealing with deciduous plants, have generally been regarded as of minor importance. We have therefore tried to avoid carrying the parallel too far.

This communication merely aims at bringing together the latest data upon the subject and at describing the most recent methods by which research workers in various parts of the world are endeavouring to find solutions to their problems.

The spade work of compiling this communication has fallen upon my colleagues, Messrs. D. Akenhead and G. St. C. Feilden, and it has only been left for me to make technical and editorial suggestions. Our hope is that T.C. 3 will be instrumental in circulating among the workers interested those too frequently isolated scraps of information which, when viewed as a whole, often go to the building up of an ordered conclusion.

R. G. Hatton.

I. VARIATION IN CITRUS ORCHARDS.

The variation in production and size of individual trees in citrus orchards is not a mere bogy of horticultural advisers but a fact demonstrated on each occasion of testing.

Thus Webber (96) writing in 1925 of South African groves gives the following opinion :—

" Some groves, particularly those 10 years of age or older, are made up in considerable measure of trees of variable types, frequently almost or quite worthless as commercial sorts. This is particularly true of the early planted Navel groves. In many orchards of all ages there are frequently variations in size of trees and in yielding capacity, many trees existing that apparently year after year are regularly low yielders or " boarder " trees.

Again Hodgson (41), in urging Californian growers to take simple tree records, notes the presence in orchards of 3 types of tree, i.e., the entirely unprofitable, the self-supporting and the profitable tree. He gives analysed figures of cropping from three orchards as follows :—

Orchard	1	2	3
Percentage of unprofitable trees	13·0	14·0	32·0
Percentage of self-supporting trees ..	19·0	32·5	42·0
Percentage of profitable trees	68·0	53·5	26·0
Total number of trees	5,736	800	1,525

It will be seen that even in an outstandingly profitable orchard such as number 1, segregation of trees into these classes shows that approximately one tree in three is either only self-supporting or is actually carried at a loss. He writes in 1923 (41) : " In the average orchard it is believed that the percentage of such trees is near 50."

Again there is the evidence of Batchelor and his co-workers (3) to show the existence of variation. In preparation for fertilizer experiments they aimed at uniformity of material, treatment, and, as far as possible, soil. To ensure uniformity of material they adopted the following methods of propagation.

(1) The sweet orange (*C. sinensis*) stock, transplanted from seed bed to nursery in 1914, was culled and undersized trees amounting to about 15 % eliminated. (2) At the time of budding in 1915 a further elimination of small sized trees was made. (3) On transplanting the budded trees in 1917 a third discarding of trees lacking vigour and size was carried out.

In budding only plump, well-formed buds from mature old wood were used, and only such twigs were used as showed blossoms formed or in process of formation on the tips of the current season's growth at the time the bud wood was cut.

And yet yield and growth records taken during the twelve years of life, from planting up to the time of first application of fertilizer treatment, revealed the existence of considerable variation. Thus there was a difference of practically 109% between the lowest yielding plot, which produced an annual average of 79 lbs. of oranges per tree for the 6 year period recorded, and the highest yielding plot which produced 179 lbs. This variation was not considered strange by the authors in comparing areas of soil one-third mile apart. But, in addition, they also found variation in production of adjacent plots amounting to 30-40%. They consider that the two groups of factors which are most persistently operative in causing the variation in production are (1) the inherent qualities of the tree due to character and vigour of rootstock and top, (2) the variability of the productivity of the soil. They comment as follows :— " In spite of the variations in the growth and production of the trees of this field, it is believed that this planting is singularly uniform in comparison with the average citrus grove. This fact has been brought out in statistical studies of the variability of this and other orchards. In appearance the trees are strikingly similar."

In an earlier study on the nature and extent of the casual variability of yields of Navel and Valencia oranges and Eureka lemons under field conditions, and its bearing on the reliability of plot trials, Batchelor and Reed (3) selected for their trials orchards uniform in treatment and appearance, and yet found considerable variability in productivity. The coefficient of

variability for the yield of individual trees of these clonal varieties ranged from 29·27±0·69 to 41·23±1·52%. Computations made on the yields of the orange trees for several consecutive years showed little annual fluctuation in their variability.

Many other workers have testified to the variations usual in citrus orchards. Thus Webber (97) in 1920 noting the existence of variation in yield of trees of the same variety in the same orchard, planted at the same time and cultivated alike, considers it likely to be due primarily to one of the following factors :—

1. Variations inherent in the buds due to different heritage.
2. Different kinds and characters of stock used.
3. The character of the union obtained in the budding and grafting.
4. Differences in environment.
5. Accident.

The influence of the stock on the variation observed is believed by him to be fundamental. He notes the normal practice to be as follows :—

The stocks are grown from seed and the seedlings transplanted from seed-bed to nursery about 12 months after sowing, at which time they vary greatly in size, ranging from a few inches to 18 inches or more, this variation being always seen. In ordinary practice all of the seedlings are transplanted or at most only a few of the smaller ones are discarded.

After another 12 months those large enough are budded, there being considerable variation in the size of the seedlings, the smaller ones being budded later.

The budded trees then wait another 2 years and are transplanted to the grove. At this time they still vary greatly in size. Quite commonly only the largest trees in a nursery will be dug and sold, while the rest will be left for a future occasion.

The smallest trees from the smallest stocks will finally reach sufficient size and ultimately find their way into the grove. He considers that the question whether this small tree is as likely to produce a good productive orchard tree as the vigorous growing one selected previously remains unanswered.

Webber describes here an experiment in which he graded out seedlings of sour and sweet orange on transference to the nursery, discarding for inadequate size about 15% of the sweet and 25% of the sour stocks.

A further grading preceded budding, when those surviving the test were budded with 4,000 buds of Washington Navel and Valencia orange and Marsh grapefruit on the sweet stocks and 4,000 Eureka lemon buds on the sour stocks. All buds were specially selected from trees of known and uniform history for the previous five years. Throughout the rest of the time in the nursery the trees gave every appearance of good growth and comparative uniformity.

Two years later the trees were regraded, 15% being rejected as undersized, while the rest were planted out. Even so the author was able to grade those remaining into 3 lots, small, medium, and large.

The Eureka lemons did not stand transplanting and the experiment with them lapsed.

Of the remainder, two and a half years after transplanting, the large, intermediate and small trees were found to retain the same relative size that they had when dug in the nursery.

An examination of other possible causal factors led Webber to consider that the most important cause of difference lay in the stocks.

He says that among rootstocks in common use such as sour orange, sweet orange, grapefruit, lemon and trifoliate, " It is known that there are hundreds of different variations, types or varieties within each."

In examination of a stock nursery of sour and sweet orange, Webber, Mertz and Thomas (97), were able to select out 16 different types of sour orange and 4 different types of sweet orange. Many more could have been selected. Two years after planting out these different types were found to be remarkably distinct from each other in character and size of growth, branching, foliage and other important characters. An examination of stocks at Berkeley confirmed these findings, so that Webber remarks : " There is no doubt that citrus nursery stocks as

ordinarily grown are made up of a very large number of widely different types of different genetic constitution, exhibiting a wide range of characters." He recommends : " When any seedling is found to be a good stock type, it can be propagated by buds and each nurseryman can grow enough trees to supply the seeds required for his nursery use."

He then gives definite recommendations to those wishing to produce uniform citrus trees. As a preliminary necessity he urges that good stock varieties of sweet and sour orange should be found, named and grown regularly to furnish seed for the production of nursery trees. [This is actually practised in the Aegean Islands and near Milazzo in Sicily. In these localities extensive, isolated areas are devoted to the raising of sour orange seedlings for ultimate use as rootstocks in an endeavour to maintain the purity of selected strains and thereby secure some measure of uniformity.—Ed.] The rest of his recommendations concern the elimination of variants by selection.

Twelve years further work and observations in California have merely served to confirm his opinions and his recommendations remain materially unchanged. In *Hilgardia* (91) for June, 1932, he writes, " in any lot of seedlings grown from seed of the same variety and from the same source, from 5—40% are highly variable types, which apparently differ in genetic constitution from the prevailing type and each other." The remainder are of the same general type, and are, he considers, probably of apogamic, i.e., asexual origin. He notes in great detail the evidence of variation and its causes and demonstrates the existence of very strong evidence that small seedlings and small budlings tend to produce, small, low-yielding trees, and large seedlings and large budlings to produce comparatively large, high-yielding trees. The most important factor is the elimination of the variant seedlings, " that are found almost uniformly to produce weak and dwarfed orchard trees."

He considers the normal methods of elimination and makes a searching comparison from an economic standpoint of pre-budding and post-budding selection, which results much in favour of the former.

Dealing with sour and sweet orange stocks and the production of good uniform trees, he recommends the adoption of the following practice in the nursery :—

Seed Bed Selection. This should consist of a discarding of the smallest plants up to 25% of the total at the time of transplanting to the nursery, i.e., one year after sowing. This would eliminate a considerable proportion of the variant types.

Nursery Selection. This should be made just prior to budding when the seedling has been 2 years in the nursery and has had plenty of time to show its top characters, and should consist of the elimination, irrespective of size, of any seedlings differing from the normal in any way and in addition of small seedlings up to a limit of 25—30% of the remainder. " After this elimination," he writes, " the entire remaining population may be budded and safely regarded as propagated on good, uniform, highly selected stocks. As the seedlings up to this time have little value, it does not entail very great financial loss."

Budling Selection. Small and inferior budlings should be removed before digging for planting out. This elimination should be very slight, with good buds and selected stock probably not more than 1—5%.

The problem of achieving uniformity in the citrus orchard has never lacked attention from Webber and it is interesting to note his experiences in South Africa.

In 1924-25 (96) he conducted a special enquiry on the citrus industry of the Union, and as a result he recommended a serious trial of vegetative propagation methods for raising not only scions but also rootstocks.

In his report he notes the proved unsuitability for South Africa of the Seville orange as a rootstock and discusses the possibilities of the rough lemon.

He considers that the lesson to be derived from his own work and experience seems clear, namely that we cannot expect to obtain uniformly good lots of trees from ordinary, unselected seedling stocks, every individual of which differs in some character. Thus, as a casual example, an examination of a group of 30 seedling rough lemon trees of about 7 years old showed 4 distinct types, strains or varieties, each of which, he considers, would react somewhat differently as a stock.

In future he concludes : " We will have to select good stock strains that by experiment are known to produce uniform seedling progeny, or it will be necessary to find good stock strains and propagate budding stocks from these by some means such as layering or by cuttings in order to ensure uniformity."

His search for good strains propagated asexually was successful.

He found that in practically all cases layered trees seemed to possess rather an exceptional vigour and fruiting capacity. Fair comparisons were made between Valencias and Navels budded on rough lemons and others growing on their own roots from layers. In no case did the layered tree suffer by the comparison. He saw no evidence of the layered trees being rooted only on one side, nor did they appear more liable to uprooting by the wind, though he did note that they had no tap roots. Sweet orange layers were indeed susceptible to collar rot, but no more so than sweet seedlings. Wherever plantings of layered trees were found they were clearly as good or better than any other trees in the grove.

The Washington Navel is in general a slow growing, rather weak tree and one could understand the failure of such a variety on its own roots. Yet some forty ten-year-old layered Washington Navel trees near Grahamstown were seen to be growing just as well as others budded on rough lemon. If then this does fairly well, sorts such as Valencia, which are naturally vigorous, should do very well.

But the method of propagating by layering as practised in S. Africa,* of which Webber gives an illustration, is not conducive to the production of a large number of rooted layers, only one tree being produced by each layered branch, nor had it been used for getting rootstocks. Despite this, Webber suggests that the use of layers or cuttings for propagating citrus stocks might prove extremely valuable and he considers that experiments might profitably be made with the method of layering so successfully used for deciduous fruit trees [i.e., pinning down and covering the young shoot, which will then root at the nodes—Ed.] A warning note is sounded by him in this connection. " This method of propagation, however, would in general give no opportunity to effectively practise bud selection, and this is a serious drawback with unstable sporting varieties like the Washington Navel and the Valencia, and is somewhat risky with any citrus variety."

Webber was thinking here in terms of own rooted trees as a possible method of achieving uniformity. The more economic practice being, however, to bud or graft varieties on to particular rootstocks, the actual problem is to achieve uniformity of production from this compound plant of rootstock and scion.† Uniformity of soil and treatment are essential. As regards the rootstocks, standardization of seedling stocks by elimination of variants in the nursery has already been touched on‡ and will be referred to again in the section on polyembryony, while details of propagation by layering, cuttings, etc., will be found in the following pages together with notes on the work of bud selection of scion varieties.

II. POLYEMBRYONY.

That variation exists within such groups as sour orange, sweet orange, trifoliate, pomelo, etc., has been shown by many workers.

Bonns and Mertz (7), moreover, who made notes on the first 5 years cropping of Valencia and Washington Navel orange and Eureka lemon on the above stocks, came to the following conclusions :—" . . . It is evident, however, that there is no ground at present for recommending any particular stock for increased yield or quality of fruit of either of the oranges or the lemon used in this experiment." They note considerable variation in cropping indeed, but this variation was not necessarily any greater between trees on different types of rootstock than between trees on the same type of rootstock. As they point out, it was scarcely to be expected that evidence would be available in so short a time, but later trials, some of which are referred to in the previous section of this memorandum, show that variation still exists at a much later date than 5 years from planting, even when every effort has been made by careful selection to ensure uniformity.

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* For description, see under layering.
† Christened " stion " by Webber, June, 1932.
‡ For details the reader should consult *Hilgardia*, June, 1932, Vol. 7, No. 1.

Can approximate uniformity of rootstock be attained, and if so, what is the easiest method ? If it can be attained without recourse to the usual methods of vegetative propagation, the problem will be much simplified. In the case of citrus the factor of polyembryony may offer a solution.

It has long been known that the seeds of certain species of citrus are polyembryonic. As early as 1719 Leeuwenhoek discovered two embryos in orange seed, but the real nature of the phenomenon as regards citrus remained unexplained until demonstrated by Strasburger in 1878 (71).

Polyembryony, or the presence of more than one embryo within the seed, may arise in various ways. In the orange it may be ascribed to a stimulus received by the cells of the nucellus, both above and below the embryo sac, even though separated from it by several cells. Strasburger found that no seeds developed without pollination, and from this concluded that fertilization of the egg cell is necessary for the formation of the nucellus embryos. The experiments of Toxopeus bear this out. Toxopeus (86) states, however, that strictly speaking his own experiments have proved only that pollination is essential and do not definitely decide the point whether actual fertilization is also necessary. The possibility remains that the stimulus may be given by the mere ingrowing of the pollen tube, though his cytological investigations strongly suggest the necessity for actual fertilization.

Neither spore nor egg cell being involved in this reproduction process, the formation of these additional embryos may in effect be regarded as a case of adventitious budding, analogous in its results to true vegetative reproduction. It follows that on germination one seedling will be a true cross, while presumably the remainder, numbering sometimes as many as ten, will differ in no way from the mother plant.

Frost (27) found that citrus seeds varied greatly both in the number and in the size and shape of the adventitious embryos contained. He thinks there must be much competition both between themselves and between them and the fertilized embryo, and that the chances of survival to germination point must depend largely upon size, position, relative age and vigour of the two classes of embryo. In it he sees a form of developmental selection, natural selection acting within the soma of the parent [the evolutionary significance of this has been discussed by Buchholz (11) in 1922.—Ed.], since genotypes inferior to the seed parent would tend to be severely handicapped by the competition of the vigorous apogamic embryos.

The economic significance of the phenomenon has not remained unobserved. Thus, if it is possible to distinguish the sexual seedling from the others in the seed bed, it would seem that nothing further should be needed to preserve a pure line of vegetatively reproduced descendants beyond the elimination of this seedling. Work by Webber (94), discussed by him in a paper at the Ninth International Horticultural Congress, seems to suggest that polyembryony can be turned to good account. Dealing with the variations seen in the seed bed and their persistence he writes, " The evidence seems thus to indicate that, if the variant types of seedlings [i.e., the generative offspring—Ed.] were eliminated in citrus at the seed bed, the remaining seedlings would show different sizes due to crowding and environment, but that the important inherent differences in growth rate, if any exists, cannot be recognized at this time. It also seems to be the case that the remaining seedlings, after the variants are excluded, would show less genetic variation than would be expected in apple seedlings after excluding the marked variants, and should thus give a lower coefficient of correlation between size of nursery stock seedling and size of budded tree." He notes incidentally that smaller correlations were obtained in his experiments than in the case of various repeated experiments with deciduous fruits.

Toxopeus (85), experimenting in Java with many kinds of citrus varieties, found the percentage of vegetative progeny arising from self and foreign fertilization in these varieties. Actually in the case of many hybrids the type of fertilization did not affect this percentage appreciably. Varieties examined included types of the following :—*C. nobilis*, *C. Aurantium*, *C. grandis*, *C. aurantifolia*, *C. medica*. As regards the elimination of generative seedlings he found that there was no difficulty in picking out the offspring of complicated hybrids at a very early stage. Thus the generative offspring from such hybrids sown in December, 1928, were

readily picked out in July, 1929. He states that, if negative selection of these off-type seedlings is made, 90—100% of the remaining plants will be of vegetative origin. This has also been found to be the case with two of the best stock varieties possessed by the Horticultural Extension Service in Java, namely Japanese citron (*C. nobilis* Lour. hybr.) (53) and Citronella = rough lemon. When on the other hand the mother parent is not a hybrid and the percentage of vegetative seedlings is known by trial to be less than 90%, the generative seedlings can be made distinguishable from the vegetative type by crossing with a very different father plant. For the pollen plant to be employed usefully, it should possess one or two characteristics, which in the resulting hybrid will dominate pronouncedly at an early age over those of the seed parent.

In a recent article Toxopeus (83) describes the method of differentiating between the generative and vegetative seedlings of Japanese citron and rough lemon. As regards the latter he notes that the generative offspring amount to only 4%, generally show very poor growth and are very easily distinguishable. The seeds produce 2 or 3 embryos which obstruct each other's growth very considerably. The weakest may be removed in the seed bed and the rest transplanted after developing their second leaves. In Japanese citron, where the percentage of generative offspring is much greater, 50—60, there is a greater danger of confusion, though to an observant eye the differences are obvious. To help those not conversant with the typical characters Toxopeus gives a comparative table of leaf and stem characteristics which mark the vegetative seedling, and the several characteristics which are likely to be seen in the generative seedling. Again, the generative plant is usually a weak grower.

As regards the hybrids themselves Toxopeus (84) has found that only a very small proportion are compatible, i.e., some 28 out of 1,400. It is interesting to note that none of these 28 had pomelo as a parent. There is as yet, of course, no evidence as to the growth and cropping of citrus varieties worked on any of the compatible stocks, but at least there is hope that some, at any rate, will by field trials be proved valuable as stocks, in which case their reproduction by vegetative methods, including selection from polyembryonic seed beds, cuttings, layers, etc., might be a source of uniform rootstock material.

Webber (93) in the current volume of the *Proceedings of the American Society for Horticultural Science* notes that apogamy, or the production of seedlings from unfertilized embryos, presents considerable difficulty to the breeder, but may be turned to good account by the nurseryman, "who should thus apparently be able to obtain easily from any good stock type large batches of seedlings, which can be depended upon to be of nearly uniform genetic type and to react uniformly on the scion." Writing in 1931 he noted, however, that the percentage of apogamic embryos in certain citrus species and varieties used as stocks varies considerably. Obviously any stocks to be perpetuated by this vegetative seedling method, however desirable their other qualities, must possess the polyembryonic factor to a marked degree. The actual range of apogamy has been determined for certain varieties by different workers, and is given by Webber (92) as follows :—

SPECIES.			RANGE IN PERCENTAGE OF APOGAMIC EMBRYOS.
Sweet orange varieties,	*C. sinensis*		40—95
Sour „ „	*C. Aurantium*		75—85
Grapefruit „	*C. grandis*		60—95
Mandarin orange „	*C. nobilis*		10—100
Lemon varieties „	*C. Limonia*		10—96
Citron „	*C. medica*		40—50
Trifoliate orange „	*Poncirus trifoliata*		72

A factor of exceptional interest is the high percentage of apogamy shown by some F 1 hybrids of radically distinct species and the fact that such hybrids are often likely to be valuable as stocks. Thus progenies of the citrange, a hybrid of *P. trifoliata* (72% apogamic) and *C. sinensis* (40—95% apogamic), have in Webber's experience always reproduced the citrange type, and may thus be considered as 100% apogamic. Among varieties which are not entirely apogamic he has found that there is a proportion of seedlings differing from the prevailing type. These variants are commonly, but not always, of comparatively small size and "almost invariably produce

some degree of dwarfing in scions grown on them. The evidence available indicates that these variants apparently are seedlings produced from the normal (sexual) embryos, probably mainly by self-fertilization. The roguing out of these variants from a batch of nursery seedlings before they are budded is the most important selection that can be made in the nursery. The seedlings remaining after such an elimination can be safely considered to be chiefly of apogamic origin."

Nevertheless, even among apogamic seedlings remarkable variations have been noted from time to time, the phenomenon being ascribed by Frost (27) to chimeral conditions in the parent trees. Thus a pollen-sterile navel orange has been known to produce apogamically several fertile, non-navel progeny. Again Webber's (92) experience during the last twelve years shows that reproduction by vegetative means does not eliminate the necessity for selection in the nursery. He finds that " within comparatively homogeneous, apogamic seedling progenies of citrus the large seedlings in general produce larger budlings than the small seedlings of the same progeny, and that this larger size is maintained in the orchard for at least several years. Trees on large seedling stocks during the first 8 and 10 year periods in the orchard have yielded over 19% more than comparative trees on small seedling stocks from the same apogamic progeny." He considers that though eventually the difference may disappear, it may be maintained for many years in long-lived, slow-growing perennials such as citrus, and may be attributed to the hold-over influence of large size and vigour in the young seedlings or cuttings. Although the heritage of such plants is unlikely to be affected by the process of selection in the nursery bed, he considers such selection to be economically sound, and gives figures to support this view (91).

Toxopeus (86), summing up the possibilities offered by polyembryony, says that it enables us in one way or another to raise in one year from a single tree a very much greater number of vegetative progeny than would be possible by methods of budding and grafting without spoiling the mother tree. Further, new varieties can be imported as seed, thus minimizing the the risk of importing disease. If the seed is found satisfactory, then by observation of the number of embryos an estimate of the percentage of apogamic offspring can be made. If this is high, a single sowing will furnish a large percentage of replicas of the mother plants ; if low, twinning will be necessary. [In twinning the seedling is split vertically in two, thus securing two plants instead of one.—Ed.]

III. VEGETATIVE PROPAGATION.

1. Cuttings.

It is not proposed to consider at length modern theory on the reasons for root and shoot formation in various types of cuttings. Priestley (62) deals fully with many of the general problems involved, Van der Lek (50) describes root development in the woody cuttings of *Ribes nigrum* and *Vitis vinifera*, while practical points on vegetative propagation of deciduous fruit tree rootstocks are discussed by Knight (48).

But before examining the differing reactions of the different varieties and species of citrus to this method of propagation it may be of interest to note the actual processes which have been noted as taking place in a cutting. Hunter (44) considers that three phases may be observed :— In the first the walls of those cells, which lie close to the cut surface, but which have not actually been injured themselves, become suberized. Fatty substances are apparently released from these cells, and these oxidize upon the surfaces of the cell walls to form a layer of suberin. This layer protects the cells from the entry of decay organisms. Suberization takes place best in an atmosphere saturated with moisture and under conditions of ample aeration. The second phase is characterized by the formation of callus tissue, which arises as the result of cell division or multiplication which takes place beneath the suberized layer. This callus tissue forms an even more efficient barrier against the entry of decay organisms. The third phase is marked by the differentiation of roots from the wood cambium and their growth outwards, piercing the callus tissue.

Factors which affect the incidence of these processes are the outer environment which surrounds the cutting and its internal, physical and chemical conditions. In Hunter's opinion one of the most important factors affecting the speed of rooting is the age of the material.

There are indications, he says, that cuttings should be made from material the leaves of which have not yet developed their full dark green colour, their stems being fairly sappy. Another factor needing investigation, in his opinion, would appear to be the size of the sand particles in the rooting bed. There are indications that the size and type of grain are immaterial if the sand can be kept adequately moist, but that in the absence of this and in the presence of coarser grades of sand a large development of callus takes place and rooting is retarded.

Work by Halma (32) has shown the great importance of the leaf for root and shoot formation in cuttings. Experiments by him with large citron cuttings without leaves and undetached lemon shoots in the orchard have shown that the amount of twig growth produced is positively correlated with the size of the cutting or undetached shoot. Moreover, by growing leaf cuttings he found that both the area and green weight of the leaf are positively correlated with the amount of roots produced. This was also found to be true of leafy twigs, which indicated that the stem itself played a minor part in the rooting of the type of cuttings used.

Halma (33) has shown that the depth of the palisade tissue (expressed as a percentage of the thickness of the leaf) is about 20% greater in the lemon than in the sweet orange leaf, is greater in the orange than in the grapefruit and least of all in the Satsuma. When it is realized that the lemon grows faster than the sweet orange and the sweet orange than the grapefruit, and that cuttings of the lemon group root more rapidly than those of the sweet orange, which in turn root sooner than those of the grapefruit, the existence of a close relation is indicated between the degree of palisade development of each species and its ability to root from cuttings, as also its subsequent growth rate based on unit leaf area until the tree begins to fruit. Halma notes that Alexandrov found in 3 varieties of grape examined that the higher the ratio of depth of palisade tissue to thickness of leaf in the variety, the more productive was that variety.

Work by Halma and Haas (35) has also established the presence of fundamental differences in the physical and chemical constitution of the sap of Eureka lemon and of Valencia and Navel orange. It has shown, moreover, that the sap of normal, mature lemon leaves is less active osmotically and contains less ash and calcium than that of oranges, and also that the sap of lemon leaves on exposure to direct sunlight becomes concentrated more rapidly than that of orange leaves.

While noting that these differences may have a bearing on the behaviour of the cuttings of these species, Halma stresses the necessity for a study of the respiratory, photosynthetic and translocatory processes before a decision can be reached.

Although the lime, lemon, citron, and trifoliate root easily enough from cuttings for their propagation by this means to be in some countries the usual commercial method of raising them, the sweet and sour orange and the grapefruit are less accommodating. Webber (98) in 1896 wrote of the difficulty experienced in rooting the orange and grapefruit, and advocated the use of bottom heat. Both Coit (17) and Hume (43) consider the rooting of these varieties to be so difficult as to be impracticable for commercial purposes. Swingle, May, and Robinson (75) in 1924 found that sour orange and other difficult citrus could be made to root by the aid of the solar propagator, which provides bottom heat and a close humid atmosphere. Halma (32), as the result of an exhaustive study of the subject lasting from 1926-30, agrees that the orange and grapefruit root less readily than the lemon, but contends that by his methods they can be made to produce a commercially satisfactory percentage of rooted plants. He gives a list of 24 citrus varieties and species propagated from cuttings. Some, like lemon and citron, root readily in any case from cuttings, but it is interesting to note that he got 92% success with sour orange and 75% with grapefruit. He finds, moreover, that cuttings root more readily when taken from vigorous than from weak trees, giving two instances of cuttings from weak and strong Valencia and weak and strong Navel orange trees.

Stem Cuttings.

Halma (32) recommends, therefore, that cuttings should be made from mature terminal shoots taken from healthy vigorous trees. They should be 10—15 cm. in length and have 5 or 6 nodes. The lower leaves should be removed, leaving 3 or 4 on the cuttings. He has found that the amount of leaf area retained has a direct bearing on the amount of roots produced. Thus single lemon leaves with a stem would root well, while bare stem lemon cuttings failed

to do so to any measurable extent. Whether the basal cuts were nodal or internodal did not appear to be significant, but there did seem to be a correlation between the angle of slope of the cut and the number of roots produced, the rule being the steeper the slant the fewer the number of roots. A cut straight across with four narrow, equally spaced grooves made at the cut end, which limited root activity to four definite places, produced the greatest number of roots, although the actual weight of roots produced per unit of leaf was not thereby increased. The cuttings should be placed in sand in a shaded, glass-covered frame or propagating pit. A minimum sand temperature of 24°—26° C, i.e., 75°—79° F., should be maintained, and this is most satisfactorily arranged by the provision of bottom heat. It is very necessary that the leaves of the cuttings should be kept turgid, and a high degree of humidity must accordingly be maintained in the propagating frames. Air should be only sparingly admitted and frequent sprinklings of water should be given. Within three or four months the cuttings will have developed sufficient roots to enable them, after hardening off by a reduction of atmospheric humidity, to be transplanted to nursery beds. This should be done bare-rooted, precautions, of course, being taken against the roots drying in the process. Any new leaf growth must be removed, but the original leaves should be left, since experience has shown that they are essential to the establishment of the transplanted cuttings. In two or three years the cuttings will have attained the size of saleable budded trees. While these specialized methods are necessary to induce rooting in orange and grapefruit, lime, lemon and citron will grow in open cutting beds without difficulty, under which conditions, moreover, Halma says that the cuttings may be larger and devoid of leaves.

In Palestine, Turner* (88, 89) states in correspondence that the method commonly in use is to set citrus cuttings in open, rarely shaded beds of sandy soil, which is kept moist and weeded. They are 35—40 cm. in length, of well matured wood, and of the thickness of a man's thumb, with 4—6 eyes not too far apart. The cuttings are inserted in February or March and begin to root in about one month. In two months top growth has started and in six months the plant is 80 cm. high, reaching 150 cm. in a year. Experiments conducted by Oppenheim at the Agricultural Experiment Station of the Jewish Agency at Rehovoth in Palestine are described in one of his articles (57). The plants were propagated both in a glasshouse having a soil temperature of 22°—23°C. (71·6°—73°·4F.) and an atmospheric humidity of 89% and in the open where the soil temperature varied from 19°—23°C. (66·2°—73·4°F.) and the atmospheric humidity was 66%. The varieties used were sweet lime and sour orange, both with and without leaves. After 38 days under glass 50% of the sweet lime with leaves had rooted and 83% without leaves ; of the sour orange with leaves none had rooted, while of those without leaves 100% had rooted. The root systems of the sweet limes with leaves are described as well developed, but all the others are classed as poor. In the open after 38 days 50% of sweet lime both with and without leaves had well developed root systems, but with leaves no sour orange had rooted and without leaves only 1·6%. The bud development in all cases except that of the sweet lime without leaves under glass was poor. It further appears from the tables available in the article that, while cuttings without leaves rooted more freely both in the open and under glass, those with leaves developed the stronger root systems. The successful rooting of leafless cuttings under glass is contrary to Halma's (32) experience with leafless cuttings of Eureka lemon. Under glasshouse conditions he failed to root more than 14% in 55 days, whereas his leafy cuttings rooted nearly 100%. He was, however, on this occasion using thin, terminal, twiggy growth, whereas he himself states that in California lemons can be successfully rooted in the open, if larger cuttings devoid of leaves are used.

In 1931 Oppenheim (56) conducted further tests with cuttings. These were planted as before in hot-beds under glass or in sandy beds in the open. Sweet lime in March in the open gave 95% success. Sour orange under glass in February gave only 2—3%, but when propagated in the open in June gave 25%. Rough lemon under glass gave 75% success, while *Poncirus trifoliata* planted in the same bed gave only 5%. Rooting was observed in six weeks, and the plants were transferred to nursery beds after two months.

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Attempts to root sour orange by means of semi-hardwood cuttings possessing leaves.

	Environment.	*Duration of trial in days.*	*Percentage rooted at end of period.*	*Reference.*
Hunter ..	Solar propagator — with bottom heat.	60	40%	R. E. Hunter, private letter, 26.6.31.
Oppenheim ..	Glasshouse ; soil temperature 22-23°c ; atmospheric humidity 89% ; cuttings inserted Feb. and March.	38	Nil.	Unpublished report on vegetative propagation of citrus trees in Palestine, 1932.
	Glasshouse ; temperature and humidity not stated ; cuttings inserted as above:	not stated.	2·3%	
	In open ; soil temperature 19-23°C ; humidity 66% ; cuttings inserted as above.	38	1·6%	
	In open ; temperature and humidity not stated ; cuttings inserted in June.	not stated.	25%	
Halma ..	Sand in propagating pit ; soil temperature 24°-26°C ; humidity high.	60—90	92%	F. F. Halma. The propagation of citrus by cuttings. *Hilgardia* 6 : 131-56.
Curator, Royal Botanic Gardens, Kew	Peat-moss and sand mixed. Cuttings placed in pots which are plunged in peat-moss in a propagating pit with a temperature of 65° Fahr.		" Would be surprised if practically every cutting did not root."	The Curator, Royal Botanic Gardens, Kew. Letter, Sept. 22nd, 1932.

It will be seen from the above table that with the half-ripened, leafy cuttings various workers have achieved widely different results. While one (56) can get under glass at most a 3% success, another (47) " would be surprised if practically every cutting did not root." This variation in results can, it would seem, be accounted for only in two ways. Either the cuttings were made from strains of sour orange which differed in their rooting capabilities, and here it should be remembered that the workers were located in widely separated parts of the world, or differences in technique or in the perfection of the appliances used were responsible.

It sometimes happens that cuttings of species difficult to root suffer from the shock of transplanting from the cutting bed to nursery row or on potting for the first time. To reduce disturbance to a minimum, Swingle, writing in the *Journal of Heredity* (74), suggests that these cuttings should be started in cylinders of paper or metal, open at the bottom to allow of aeration. The cuttings can then be transplanted in the containers with little or no shock. It is not explained whether the containers are to be plunged in sand in the propagating pit, but to do so would be to follow the usual nursery practice when small pots are employed in a similar fashion. In this case, as the cylinders are to be open at the bottom, care should be taken when plunging that the open bases of the cylinders rest on the bottom of the propagating pit. Should this not be done, the roots may emerge from the cylinder into the underlying sand. With difficult subjects in England, such as walnuts for instance, a small pot is filled with sand and the cutting is inserted in sand, down the side for the purpose of aeration, and the pot plunged in a propagating pit. When rooted the cutting can be gently knocked out of the pot with a little ball of soil attached and, provided it is at once replanted with the ball intact, no shock whatever will be felt.

Leaf Cuttings.

Halma (32) in the course of his investigations on citrus cuttings used leaf cuttings, and he stresses the necessity for the retention on stem cuttings of adequate leaf area. He does not, however, discuss his results with leaf cuttings. Hunter (44) has recently tried two types of leaf cutting. The first consists of a leaf and leaf stalk, the latter being cut through. A much longer time is taken to root than is the case with semi-hardwood cuttings and a considerable time elapses before any shoots are formed. These eventually appear as tiny shoot buds upon the callus developed from the cut end of the stalk. The second type includes leaf and stalk and a slip of the stem in addition and has been found much more successful. In two illustrations given by him it is seen that in a rooted leaf cutting of citron propagated in this way the roots arise from the slip of stem, while in a similar cutting of the Rangpur lime the shoot developed from the bud in the axil of the leaf. His investigations to date favour propagation by this method of leaf cutting, and he notes in this connection that leaves are available in large quantities from a given quantity of material, take up very little room in the propagating frame and root in about the same time as semi-hardwood cuttings.

Successful experiments with leaf cuttings have been made in Florida. Leaves of lemon (*C. Limonia* Osbeck), with petiole only attached, rooted in 12 days in sand in a solar propagation frame. In 11½ months they developed into twiggy shoots bearing 12 leaves (26).

Root Cuttings.

Propagation by ordinary root cuttings has not as yet been widely practised, nor has striking success been achieved with this type of cutting.

The method adopted by Hunter at Trinidad was as follows :—Cuttings 6″ long were taken from the roots of 2—5 year old trees running horizontally at some 8″ below ground. The root pieces were set in sand in the solar propagator and were placed in a horizontal position covered with 1—2″ of sand. Very little success was obtained with them. Hunter suggests that excessive rotting which occurred might be avoided and successful propagation achieved by the following precautions :—(1)the use of coarse sand for the rooting bed, (2) the very careful control of the watering, and (3) the use of a considerable degree of bottom heat. He considers, however, that the necessity for such measures rules out the system for practical purposes.

Halma (32) had no greater success with ordinary root cuttings, entirely failing to get roots, despite attempts to stimulate root formation by the injection into the root pieces of solutions of potassium permanganate, glucose, cane sugar, thiourea, sodium nitrate and calcium nitrate. He did, however, have better success with the following methods :—A healthy, leafy twig of the type used for a cutting (lemon being preferable to orange or grapefruit) is grafted on to a piece of root 10—15 cm. long and about 1 cm. in diameter. If the root piece is big enough and the bark slips, bark grafting is preferable, otherwise he recommends the tongue graft. The union is tied with raffia and the whole treated like a cutting, sealing with wax being unnecessary. Union formally takes place within 1 or 2 weeks and rootlets appear in 2 weeks. After 3 months the rooted plants are transferred to the nursery.

The process would not seem to be very suitable for the rapid production of trees identical with the root piece variety, since Halma states that the removal of the scion, a procedure which would be necessary to induce sprouting if the rootstock alone is to be propagated, before 2 years have elapsed is fatal. He suggests that a preferable course is to sever one of the young roots formed from the old root piece, and raise its cut end above ground. [Would not an even quicker process be to sever one of the roots of the original tree which it was wished to reproduce, as is sometimes done in the case of the West Indian or Mexican lime and the Kusaie lime in Hawaii (59) ? These can be propagated from root sprouts, the method being to dig out a surface root and sever or partly sever it from the parent, the severed end of the detached portion being left protruding above ground. This severed portion will often produce shoots and can be dug up and transplanted.—Ed.] If sprouts fail to develop, the mother plant is still available for further use. The best time for forcing sprouts would appear to be spring.

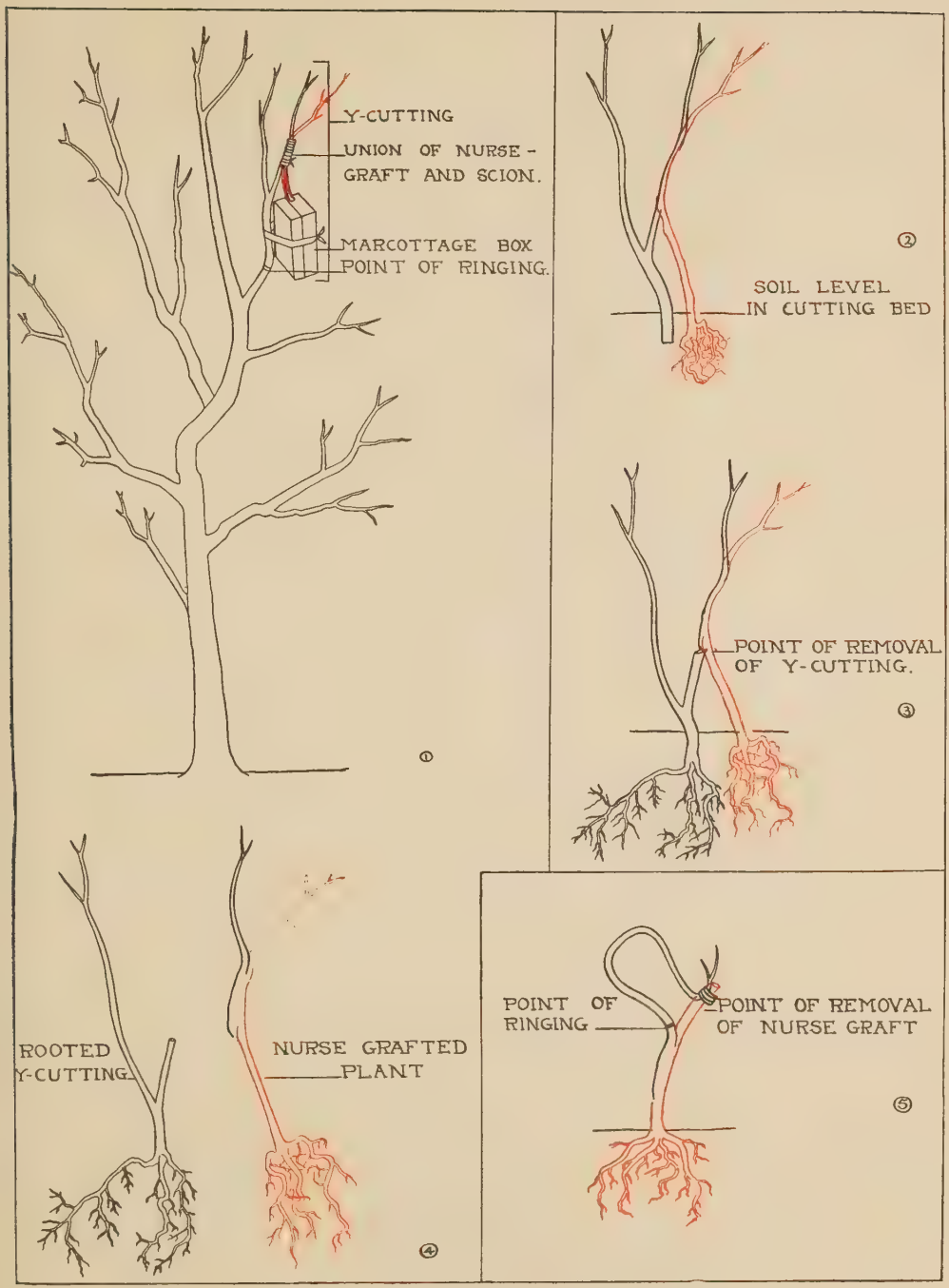
In any case the percentage of success with the method, even using root pieces from the same tree, varied much more than with twig cuttings. Examined after the success or failure of the operation the tracheæ of the successful root pieces were found to be normal and free from obstruction, while those of unsuccessful root pieces were plugged with a gummy substance. Further observations showed that roots containing gummy deposits are most prevalent in the upper 30 cm. of soil and also that roots repeatedly mutilated by cultivation always show this abnormal condition.

The Y-cutting Method.

Swingle (75) found that while a number of citrus varieties (including sour orange) and citrus relatives would root freely in a propagating pit with some bottom heat, the type of cutting being preferably leafy, terminal twigs of half ripened wood, certain other varieties proved refractory. Among the most difficult of the commercial varieties were the sweet orange and Satsuma. In 1926, however, Robinson (74), who was working with Swingle, devised a modification of a method of nurse grafting which had been used with success by Oliver (55) for mangosteens. It is claimed that this method has never yet failed with any citrus plant. By it two plants, one grafted and one on its own roots can be obtained at the same time. The process consists of approach grafting, or, as it is often called, inarching a seedling of a Y-shaped leafy branch of the tree that it is desired to propagate. The roots of the attached plant which will eventually serve as a rootstock are kept fresh by encasing them in a packet of moist sphagnum moss wrapped in waxed paper and watered when necessary and tied to the mother plant for security (Fig. 1). [Recently a small marcottage box to hold the roots has been brought out and patented, the free use to the public being guaranteed under U.S. Government patent 165573. It consists of a wax-coated paper, fibre or metal box in two parts which fit together telescopically and enclose the root of the stock packed in wet moss, the stem passing through a close-fitting slot at one end. This box ensures moisture conditions with less attention than is required by the paper packet.—Ed.] In two weeks the Y shaped scion and the nurse graft will have begun to unite. The Y branch is then completely ringed below the fork of the Y, $\frac{1}{8}$—$\frac{1}{4}$″ width of bark being removed. This causes at the point of ringing an accumulation of the reserve food material moving down from the leaves, a condition which favours the speedy production of roots when the cutting is eventually planted. In four to eight weeks, when union with the nurse graft is complete, the Y branch is cut through at the ring (Fig. 1), the root of the nurse graft is released from its waxed chamber, and both it and the forked cutting still attached are placed in a rooting medium in a humid, bottom-heated propagating pit (Fig. 2). The leafy top of the nurse graft is no longer required and is cut back to near the union with the Y branch. Soon the Y cutting will begin to put out roots and it will become necessary to separate the rooted portion of the Y from that attached to the nurse graft. This is done, usually after a month in the propagating pit, by nicking the branch of the Y carrying the nurse graft and deepening the cut every few days until final severance, contingent upon the cutting being well rooted, four weeks later (Fig. 3).

Thus two independent plants are now in being, the one upon its own roots the other on a rootstock (Fig. 4). The process is capable of still further development, for, should the plant on the rootstock be also preferred on its own roots, it can be so contrived. In this case the branch of the Y carrying the nurse graft should be of sufficient length to bend over and inarch to the top of the cut back stump of the nurse graft, the stump being left long for the purpose (Fig. 5). The scion is now joined to the nurse plant in two places, and as union proceeds it is ringed as before just above the lower union, leaving it when severed at the ring still attached by the top to the nurse graft. As before, the nurse graft and its cutting are plunged in the propagating pit, the cutting being gradually detached as root formation proceeds.

In the making of nurse grafted Y cuttings the process of rooting the cutting can often be hastened and made more certain by fitting a marcottage box or moss wrapping at the time of the operation at the point at which the cutting is ringed.



The Nurse-Grafted Y-Cutting Method.

In the event of small plants to act as nurse grafts not being available, one arm of a Y shaped branch of the plant to be propagated can be inarched to another shoot of the same mother plant. The base of the Y shaped branch is then girdled and finally detached as already described. The detached end is then placed in the propagating pit, still attached to the mother plant. An aperture in the pit will have to be made to take the branch of the mother plant holding the graft, the opening round the branch being stopped with cotton wool. This is purely an emergency method suitable for a greenhouse, since the mother plant would have to be in a pot. Swingle used it successfully with *Punica protopunica* Balf., a rare pomegranate which is not compatible as a graft with the only other species.

Y cuttings from tall trees, where a nurse graft is inconvenient to use, can often be rooted by detaching the cutting and grafting it on to a suitable stock in the propagating house, while at the same time the base of the Y cutting itself is placed in a rooting medium. The modification is naturally not so certain in its results as when a nurse graft is used.

Swingle, in discussing the reasons for the superior rooting powers of the nurse grafted Y cutting over the ordinary cutting, considers that the leaves of the Y cutting are kept in condition to carry on photosynthesis by the water supplied from the roots of the nurse graft. That water will move in the zig-zag N shaped course necessary to reach the ungrafted arm was proved by Hales (31) over two centuries ago and confirmed by Swingle's own experiments. When it comes to the return flow of the manufactured food material, this is mainly directed straight down the stem to the base of the cutting. Jost's (46) experiments on ringed trees, in which descending products of assimilation failed to pass the horizontal bar of a step-shaped ⌐ bridge connecting two parts of the ring, are considered as evidence that there is in the nurse graft cutting a " veritable trap-action " permitting the ascending flow of water but barring the translocation of the descending elaborated food stuffs to the nurse graft, these being consequently directed downwards to the base of the cutting, where they are responsible for the root formation. It is also thought probable that a certain amount of food material from the grafted arm, elaborated from material supplied by the nurse graft root, travels in part down the side path formed by that part of the cortex of the Y cutting which has remained intact at the grafting point into the base of the Y cutting, thus forming an additional source of nourishment to the cutting roots in process of formation.

An ingenious method of getting the orange on its own roots is practised in the Province of Valencia, in Spain (74). A twig of citron is side-grafted on to the orange shoot to be propagated which remains on its tree, the citron scion being kept in fresh condition by a wrapping of waxed paper. As soon as the two have united the orange shoot with the citron graft attached is cut off and planted as a cutting. The citron is a variety that roots very easily from cuttings. In the space of about 12 months it will be found that the orange twig will also have rooted. The citron graft and roots are then cut away, leaving the orange to grow on its own roots.

The advantages and disadvantages of vegetatively raised trees.

The chief aim of vegetative propagation being the production of uniform trees, Halma (32) summing up for and against " cuttings and budded trees," is most relevant. By " cuttings " he means trees on their own roots raised from cuttings.

He considers that the advantages are :—

(1) Cuttings can be taken at any time of year.

(2) There is a saving of time, as cuttings can grow *in situ* until big enough to plant out in the orchard ; moreover, they receive no such check as is experienced by the lopping of the rootstock head in budded trees.

(3) If a tree on its own root is killed back to the ground, a sprout from any living part of it will be the same variety.

Disadvantages :—

(1) More material is wanted than for bud wood.

(2) The susceptibility of certain varieties to disease may make the use of cuttings inadvisable. Thus lemon cuttings could not be grown successfully where Pythiacystis gummosis is prevalent.

Doubtful features :—

(1) The root system of cuttings is shallow, at least for the first two or three years, so increasing danger from wind.

(2) Cost may or may not be greater.

(3) It is doubtful whether greater uniformity will thus be achieved. If sweet orange, which is highly apogamic, is grown from seed, it is to be expected that most of the selfed offspring will be identical in genetic constitution with the seed parent, and that most of the differences among them will be due to the same " accidental " causes as with cuttings. Hence, the variation among such seedlings and among cuttings should be about the same. Moreover, disregarding environmental influences, the amount of variation in growth of cuttings is shown to depend to some extent on the total original leaf area of the cutting, just as the variability of the apogamic seedlings is doubtless affected by differences in size of embryo.

[In considering these doubtful features it may be pointed out that susceptibility to wind damage has frequently been imputed to trees of all kinds grown from cuttings. The editor often heard this particular objection raised to the use of citrus cuttings in Sicily in 1932. In the early days of deciduous rootstock investigation, moreover, it was urged that all layered or stooled rootstocks would blow over easily by reason of their shallow rootedness and lack of tap root. This supposition was later proved to be ill founded.

As regards greater uniformity it may be stated that exact comparisons are as yet lacking.

Touching the probable influence of the amount of original leaf area possessed by a cutting, it is granted that the influence on the growth of the cutting into a tree and on the tree's subsequent growth may be considerable ; at the same time it is difficult to see how it can effect the innate character possessed by the rooted cutting or any influence it may have, if the resulting plant is used, not to grow into a tree, but as a rootstock.—Ed.]

2. Layering.

One method of layering is described by Webber (96) in his survey of the South African citrus industry in 1925. In the Transvaal and Cape Province large numbers of old trees were found which had been propagated by layering. He was surprised to observe that layered trees were often by far the best trees in the grove both for thriftiness and vigour of habit and for sweetness of fruit. He accumulated evidence to show that the habit of growth, vigour, length of life and other characters were just as satisfactory as in the case of seedlings. The method of layering responsible for these trees was the old-fashioned, somewhat cumbersome one of pegging down and burying the partially severed branch of a tree probably already of full growth.

The theory that trees layered in this way produce roots on one side only has been found to be erroneous. A further objection raised and applicable to all layered trees that such trees do not possess tap roots is deprived of point by Webber's note that budded trees ordinarily planted are similarly without tap roots. A tap root may, in fact, be definitely undesirable in wet localities. Webber quotes a letter from a well-known grower to that effect. The grower claimed that, whereas on certain swampy lands seedlings quickly and invariably died, layers grew away well and for the planting up of clayey, retentive soil he greatly preferred well rooted layers to worked seedlings.

The aim and result of this particular type of layering is, of course, the production of own rooted trees and it has not been used for the production of rootstocks as such.

A method of layering in use at East Malling for the propagation of rootstocks of apples and other deciduous fruits has been applied with success to citrus in Java by Ochse (54). The plants to be propagated are planted as year-olds in a slanting position forming an angle of 40° with the ground. When they have become established they are bent over and pegged down in a shallow trench running along the row. As the buds begin to swell along the shoot they are lightly covered with an inch of soil and, as growth proceeds, they are earthed up by degrees until the soil covering is about 6 inches deep. It is important that the lower portion of the growing shoots should be kept entirely in the dark until rooting has taken place, and the soil must therefore be prevented from washing away. If, however, too deep a covering is given at the outset, the buds will not break. Hence earthing up must keep pace with growth until the etiolated stem, which will produce the roots, has attained the requisite length. When rooted the resulting plants are detached from the layers, which are then left uncovered till the buds begin to swell the following season. Any shoots which have failed to root or are not required can be laid in with the old layers the following season.

3. Stooling.

A system of propagation reported on favourably by Oppenheim (56) is one referred to by earlier writers (82) and described by Höstermann (42) recently as being successfully used in the Argentine for difficult subjects including a large number of citrus varieties. Höstermann calls it the Dahlemer Drahtungsverfahren (Dahlem wiring method). Oppenheim's wiring experiments were carried out in 1931, beginning in April. The plants used were trifoliate orange (*Poncirus trifoliata*), sour orange (*C. Aurantium*), and sweet lime (*C. aurantifolia* var. Swingle). Year-old seedling plants were cut back to within 20 cm. of the ground in early spring. In six weeks' time new shoots had sprung up and were large enough for treatment. Two-thirds of the shoots on each stump were dealt with, the remainder being left to carry on their natural functions and maintain the plant in health. The treatment consists in winding a thin copper wire three or four times round the stem of the shoot about 7 cm. from the main stump. When first put on the wire must not be tight enough to injure the bark. After wiring, earth is mounded up round the tree to about 15 cms. above the rings and kept moderately moist. As the shoots continue to swell, the wire penetrates the bark, usually within a month ; rooting has begun in two months through the bark above the wire, and in four months a useful root system has developed. Below the rings the shoots do not thicken ; a sweet lime wired in April was in December found to have a diameter of 17 mm. above the ring and only 6 mm. below. An advantage of the method is that owing to slow penetration of the bark by the wire open wounds are not made and there is no danger of infection. In the ordinary citrus cutting the roots appear to grow from the callus itself, though in reality they start above the callus and grow downwards between the bark and the wood, only becoming visible after penetrating the callus. In the wire-bound branches the roots grow directly through the bark above the ring and are stated to be far better developed than those of cuttings or even seedlings of the same age, as is indeed the whole resulting plant.

It is true that sweet lime can be made to root merely by mounding the soil around it, but the roots are weaker than those produced when the wiring ring system is used, while the difficult sour orange and trifoliate root successfully when treated with the rings but give no response without them. Höstermann actually found it possible to conduct grafting and rooting operations simultaneously. He budded or grafted stems of certain easily rooting subjects at the time of wiring, so that in a few weeks the new complete plant comprising rooted stock and a growing scion was ready. In view of Oppenheim's experience the method appears to merit extensive trial,

4. Marcottage.

Familiar to all workers in the tropics, marcottage is described by Bailey as a method of rooting rigid stems by surrounding them while in their natural position with earth, moss, or similar material. The stem is wounded, commonly girdled, and a divided box or pot filled with earth placed round it. The roots start from above the girdle and, when they have filled the pot, the stem is severed, headed back and planted. Hunter (44) achieved considerably greater success recently in Trinidad by wrapping with moss enclosed in rubber tubing than with sand and grit encased in coconut fibre. In both cases watering was done daily, but only by the first method was sufficient moisture retained. He found that it mattered little whether marcottage was done on stems of $\frac{1}{4}''$ diameter from the last growth cycle or 1″ stems of older growth, nor was the position of the ring in relation to the buds on the stem, nodal or internodal, found to be material. The method though successful with all varieties of citrus is clumsy and laborious and appears unlikely to become commercial.

IV. THE SCION.

1. The Choice of Bud Wood.

In Section I the variation in citrus orchards was noted and found to be due partly to soil and environmental conditions, partly to inherent differences in the citrus plants themselves. These differences may be divided into those inherent in the rootstock and those which arise in the scion. Possible methods of achieving uniform material have been discussed and in this section a few notes are given on the care necessary to prevent the loss of uniformity once it is achieved.

The importance of bud selection would not appear to have been fully realized until the increasing variability of products from Californian orchards led to the investigation of bud mutation in citrus by Shamel (68) and his co-workers.

Careful observations disclosed the fact that many orchards, supposedly of one particular variety of citrus only, e.g., Washington Navel orange, Lisbon lemon, etc., contained not a few trees differing in one or more definite characteristics from those of the normal, accepted type. Naturally those variations which were due to soil, climatic or other environmental factors persisted only in the vegetatively reproduced progeny in the presence of like conditions. But where these alien characteristics were found to persist always in the budded progeny of such trees, the trees in question were designated by Shamel as different "strains", the word "strain" being used "to designate a group of individuals of a horticultural variety differing from all other individuals of the variety in one or more constant and recognizable characteristics and capable of perpetuation through vegetative propagation."

The incidence of such strains, which were in nearly every case inferior to the varietal type, may be attributed without hesitation to the unintentional propagation of bud mutations. If Shamel's opinion as to the normal practice of bud selection prior to his investigations is correct, the apparently unnecessary error can be well understood. In the absence of knowledge or even suggestion of bud mutation taking place in citrus, a Washington Navel tree remained a Washington Navel tree and did not develop any extravagant features of branch or fruit, nor did its vegetative progeny. Hence bud wood was taken from any healthy tree of the variety, and since, theoretically, all trees were inherently identical, such a tree need not have come into bearing. Thus little or no selection was made, and bud wood was in the main chosen from suckers or unusually vigorous non-bearing branches. This led inevitably to the propagation of an ever-increasing proportion of trees of those strains, which produced the largest amount of sucker growth. Shamel notes that such trees are usually light bearers and produce inferior fruit. Moreover, when fruit wood was used for propagation, it would often be cut from branches bearing no fruits, so that sometimes buds from sporting limbs were used, resulting in the raising

of various differing strains. Thus one sporting limb might give rise to a large number of new trees, which again might be used as a source of bud wood.

It may be of interest to consider very shortly some of the important strains found by these American workers.

Washington Navel Orange. Thirteen strains were found, the following being considered the most important :—Washington, Thomson, Australian, Golden Nugget, Unproductive, Corrugated and Dry. The Washington may be considered as the true type, possessing superior commercial and eating qualities. The others should, if possible, be discarded.

Valencia Orange. Out of thirteen strains found only the Valencia is worth retention. The remainder include :—Corrugated, Ribbed, Long Unproductive, Rough and Sporting (or Variable).

Eureka Lemon. This variety was shown to include :—Eureka, Shade-Tree, Dense-Unproductive, Pear Shape and Variegated ; the Eureka alone being worth keeping.

Lisbon Lemon. Groves were found to contain Lisbon, Open, Dense-Unproductive, Bull, Variegated and Sporting (or Variable) strains.

Marsh Grapefruit. Seven strains were discovered, including Marsh, Alternate-Bearing, Rough-Seedy, Smootn-Seedy and Unproductive.

The characteristics of these strains, implied in the name given to them, might lie in habit of growth ; in productivity or habit of bearing ; in shape of fruit, making packing difficulties ; in peel consistency, spoiling appearance ; in seediness of fruit ; in colour ; in such peculiarities as persistency of style, which being liable to damage might mean the entry of decay organisms into previously healthy fruit.

Chace and Church (12), found, moreover, that the composition of the progeny of various strains of the Marsh Grapefruit differed in the amounts of peel, oil, insoluble solids and acid contained in the fruits.

Comparative tests by propagation of bud wood from all the above strains showed the persistence of their particular characteristics in their vegetative progeny in an overwhelming majority of cases. The characteristics were, moreover, present to the same degree in the progeny as in the strains. Thus the corrugated skin characteristic of one strain of the Washington Navel was variable in its incidence both in the strain and in the vegetative progeny. In the same way characteristics always present in the mother limb were always present in the progeny tree.

The Propagation of Particularly Good Strains.

It is obvious that bud mutation must sometimes show itself in superior and not inferior characteristics, resulting in strains intrinsically more desirable than the typical strain. The question arises as to whether such mutations should be used for the propagation of more desirable strains. An example of the successful commercial introduction of one such strain is recorded y Tanaka, T. (80).

Among Satsuma oranges in Japan the Wase undoubtedly arose as a bud mutation of the Owari variety. Tanaka notes that the value of Wase production rose in the twenty years previous to 1922 from nil to some £16,000, annually. It is liked particularly on account of its early ripening habit and its remarkably polished, large fruits. The fly in the ointment is, however, indicated by Tanaka's statement that it is subject to reversion to the Owari type. Such a tendency is obviously of the greatest importance and detracts from the value of the Wase.

It must also give pause to anyone proposing to propagate a newly discovered " strain " on a commercial scale. In the first place he must be sure that he is dealing with a " strain " and not merely with an environmental phenomenon. A determination of this can only be made by

propagation of the supposed mutation and observation of its vegetative progeny in comparison with those arising from buds taken from normal branches. And secondly, he must be able to propagate in adequate quantity to put on the market in bulk without mixture.

The primary object of the producer is the regular production in quantity of a standardized product, whether it be orange, grapefruit, lime or lemon. The Californian growers have taken Shamel's advice, have isolated and propagated only the best strains, eliminating the remainder by top-working or replanting, and in consequence they now produce unsurpassed, standardized fruit.

The conditions obtaining in the citrus orchards of California investigated by Shamel and now largely remedied are not confined to California. Thus Shamel says that in the best groves in that State he found 10% of the trees off-type, while the worst orchards contained 90%. Writing in 1926 Clark Powell (61) states that in South Africa the best grove to his knowledge of Washington Navels in that country contained 20% off-type trees, while in the worst every tree was off-type. He puts the average percentage of off-type trees in the Union as 33. Again in 1930 (60), he notes that Shamel found 25% of the trees in Californian Navel groves studied by him to be off-type and adds, "There is no reason to believe that fewer off-type trees exist in South Africa."

Wherever detailed records have been taken in citrus growing areas, it would appear that many undesirable strains have crept into the orchards. Such strains can be replaced by top-working with budwood taken only from trees of known performance, the vegetative progeny of which have submitted to prolonged tests. Where, as in certain parts of the Empire, Government Citrus Nurseries or Co-operative Societies, acting under the ægis of Agricultural Departments exist, bud wood should be obtainable from these sources.

2. Scion Influence.*

In studying the influence of the scion on the stock, Haas and Halma (29) found that in citrus the soluble magnesium, expressed as a percentage either of the dry matter or of the soluble ash of the trunk bark, is lowest in the lemon and sour orange and highest in the sweet orange and the grapefruit. The values found in the bark of the stock vary according to the scion variety. If sweet oranges or grapefruits are worked with a lemon scion, which normally has a low value, the values for the stocks are found to be much below those of the unbudded control trees. Conversely, if a sour orange with its low magnesium value is budded with the high value sweet orange or grapefruit, the value of the sour orange stock becomes higher than it would be if a lemon were the scion.

In Japan interesting work has been done by Tanaka, Y. (81) on the influence of scion on seedling rootstock of trifoliate. He finds that, when compatibility between scion and rootstock is perfect, the habit of the scion is strongly reflected in the mode of growth of the roots [cf. the work of Roberts (64,65) and Swarbrick (72) on apple stock-scion relationships.—Ed.]. Thomson Navel and the Japanese variety, Hyuganatsu, are not congenial to trifoliate, and consequently development of top and root is poor. Valencia, Washington Navel, Satsuma, Villa Franca lemon and several of the Japanese sweet oranges each have their own distinct action on the trifoliate rootstock. Generally speaking sweet oranges produce a deep-rooting stock, while the lemons cause shallow rooting, the colour of the roots themselves being lighter than when sweet orange scions are used. The angle between the main and lateral roots, too, is described as corresponding with the angle of the scion branches; for instance, worked with the sweet oranges generally, which have branches set at sharp angles, the trifoliate develops its roots at similar angles, whereas with the lemon the roots lie at broad angles corresponding with the set of the branches, and it is further claimed that each scion variety develops its own particular root angle which is constant for that variety.

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* For stock influence on scion *see* under particular stocks.

Webber (96) ascribes the occasional incidence of trifoliate being killed back to the ground by frost to scion influence.

The same authority notes in a later work (91) that he has himself seen numerous cases where the size of the root system was doubled or quadrupled by the reaction of different scions.

Robertson Brown (9), moreover, reports and gives illustrations of extraordinary alterations induced in the vigour and to a lesser degree in habit of various rootstocks by different scions.

V. ROOTSTOCKS.

Numerous rootstocks are used in the propagation of citrus trees, the choice being governed by local conditions of soil and climate, susceptibility to disease and compatibility with the intended scion variety. A stock which may do well in one country may fail entirely in another, as for instance the well-known case of the sour orange and its failure in S. Africa. The stocks of commercial importance at the present day are sour orange, rough lemon, trifoliate orange, sweet orange, sweet lime, and pomelo, while a number of others are under trial in various centres. In general the feeding roots of citrus are comparatively large and abundant, and replace themselves easily when damaged. They are totally (17), or nearly (24), devoid of root hairs. Each variety, however, has its own peculiarities of growth which may have effect on its suitability or otherwise for any given district. For instance, should the tap root of nursery plants be cut, as it usually is, on transplantation, the sour orange stock will send down two or three more as substitutes, while the sweet orange stock will produce only laterals. The grapefruit shows considerable variability in this respect.

1. Rootstocks in common use.

Sour or Seville Orange (*C. Aurantium* Linn).

According to Hume (43), seventy-five per cent of the world's commercial output of citrus fruit is grown on the sour stock, and Coit (17) seems to think that it would be as well if the remaining twenty-five per cent were also so grown. It is compatible with the majority of citrus varieties grown in most countries.

The sour orange is characterized by abundant and deeply penetrating roots. Hence in Florida (17) it was found to be less affected during periods of protracted drought than more surface-feeding varieties, since its deep-rooting habit enabled it to reach a fairly permanent water supply. It withstands irrigation conditions well (16) and is universally considered to be the stock to use on heavy or wet soils. Here it might be mentioned that Mills (52) considers the sour stock could be still further improved by selection for the most suitable rooting tendencies, having noticed that some produce more lateral roots than others and that those lateral producers always bear the biggest crops. With the new improved methods of propagation which are described elsewhere in this publication rapid propagation of selected varieties should not be difficult. The comparative immunity of the sour orange to foot rot and all those forms of gum disease (7, 16, 17, 24, 43), which have devastated so many orchards in the past, is a factor which must tell heavily in its favour when choice of root stocks is being considered. It is true that the sour orange is extremely susceptible to citrus scab (*Sphaceloma Fawcettii*) and that much damage may be done in nurseries by the stunting of young trees intended for use as stocks. But scab can be more or less controlled and the susceptibility of the rootstock is not communicated to scions of varieties not otherwise susceptible. In hardiness it comes second only to trifoliate, and, should the top of a more tender scion be frozen back, sour stock will sprout readily, so that it is not difficult to renew by rebudding (7, 43). In the early years, trees on this stock are not very free bearing, but the fruit that is produced is of good quality from the start, a characteristic which is not common to the quick-growing stocks (7, 17) such as the rough lemon. In Egypt (10) trees on sour orange are somewhat dwarf and of comparatively slow growth. It is also in that country supposed to retard ripening and to accentuate any tendency of the trees to biennial bearing. Nevertheless, except with certain scion varieties which will be

mentioned later, it is regarded as one of the safest stocks to use. In South Australia (63) it is considered that there is a pronounced dwarfing effect, particularly on land tending to dryness, but its use is recommended on retentive soils. As a stock for lime the sour orange has achieved such notable success in Dominica (20), that it may come to be regarded as the saviour of that island's lime industry. A series of hurricanes had severely damaged the plantations which consisted entirely of seed grown trees, and the *coup de grâce* was given in September, 1930, when the worst hurricane in living memory devastated the island. On many plantations scarcely a tree was left standing, and of those not immediately destroyed many thousands have since succumbed to the epidemic of Red Root disease (*Sphaerostilbe repens*) which followed (38). In this supreme disaster, however, as in the previous ones, limes which had been budded on sour orange withstood the fury of the storms, suffering, on estates where seedling trees were blown down wholesale, little more than the loss of the crop, while young budded plants set out a few months before the storm were practically unaffected. Comparing budded limes on sour stock planted in 1913 at the Experimental Station, Dominica, with seedling limes planted at the same time and under the same conditions, the budded plants have throughout made much the more vigorous growth, and have borne correspondingly heavier crops, while the fruit has a higher acid content. Limes on sour stock have emerged unscathed from disasters of disease and storm that have completely laid low the seedling limes surrounding them. So well have the advantages of the sour stock for limes been demonstrated that the use of the seedling tree has now been entirely discontinued by growers.

The Dominica lime, a spineless variety of the West Indian lime, found in Dominica in 1891 and for a number of years the standard variety, was until the introduction of the sour stock always grown from seed, producing a very uniform type, about 75% coming true. This lime, however, is no longer planted owing to its susceptibility to wither tip, but a new seedless lime of which the Agricultural Department of Dominica has great hopes has been discovered and is being propagated on sour orange (38).

As a stock for lemons the sour orange is used with complete success in Italy (15) [almost to the exclusion of all other stocks.—Ed.]. Webber (96) notes that it is fairly successful in South Africa as a lemon stock, though rough lemon stocks are more commonly used. But Blanchard (6), writing in 1931 in the *California Citrograph*, discusses in some detail the fact that after about 10 years lemons on sour stock in certain parts of California, notably Ventura county, often appeared to go into a decline with yellowing leaves and general sickliness. This he ascribes in the main to stock influence, though he considers excessive irrigation to be partly responsible.

As regards grapefruit, sour orange is the stock advised for the rapidly developing grapefruit industry in the Imperial Valley, California (22).

Its one conspicuous failure on a large scale is in South Africa (96), as a stock for oranges, and the numerous groves once planted with it on the strength of its success in other citrus countries have gradually disappeared, so that Webber during his survey in 1925 was unable to find more than a few trees still living, none over 20 years of age and all dwarfed and worthless as bearing trees. He endeavoured to determine the cause of the failure, but was unable to find any reasonable theory. It cannot, he says, be due to a bad stock type, since budded trees on tested stock have often been imported into South Africa from California and Florida and planted under the most favourable conditions, yet all have failed to grow into productive trees and have died more or less speedily. The mystery becomes even more profound, when it is considered that seedling trees of sour orange grow and crop there with normal vigour, while, as previously noted, it is fairly successful as a stock for lemons. Webber suggests that the Seville orange is so variable (he once selected twenty different varieties from a supposedly uniform rootstock stand in California), that it might be possible to find one that would respond to South African conditions as a stock for general use and so provide the immunity from the very prevalent collar rot which the rough lemon, now the stock almost exclusively in use, cannot give.

Sour stocks fails also with the kumquat (43, 10), and in Egypt with the sweet lemon of Egypt,* and with some of the seedless lemons (10). Similarly in Egypt (21) the Washington Navel is not found to be a prolific bearer when worked on sour orange.

Whether owing to climate, soil, cultural practice, variation in scion variety or in the sour stock used, or to a combination of the above, experience as to its merits as a stock differs in certain cases from country to country. Thus speaking of conditions in Florida Hume (43) describes it as being incompatible with Satsuma orange, with kumquat, limequat and with lime, while Swingle (2) says "that the sour orange is a congenial stock for all important varieties, Satsuma alone excepted." Yet Robertson Brown (9) states and backs his statement with photographic evidence that in N.W. India the Sangtara (=Satsuma) does well on sour stock, forming a compact and vigorous tree. Moreover, the incompatibility with lime just noted runs contrary to experience in Dominica, assuming the same variety of lime to be intended, which is presumably the case, since Hume further says that the West Indian or Mexican Lime is the commonest variety in Florida, though he adds, incidently, that being grown from seed it is a very mixed strain producing fruits of all sizes. Again its failure with the Malta orange in N.W. India compared with its success with this variety in the United States affords a further notable contrast.

Sweet Orange (*Citrus sinensis*).

Sweet orange would be far more extensively employed as a stock, were it not that its extreme susceptibility to mal di gomma or footrot exceeds that of any other citrus stock and renders it unsafe to use on any but light and dry soils; moreover, since other more resistant stocks will also do well on these soils, the use of sweet stock with its attendant risks has in many places been discontinued. A characteristic of the sweet stock is the shallow root system, the main mass of which concentrates in a horizontal layer about 18 inches thick, the top being about 10 inches under the surface. Mills (52), who investigated the root systems of various citrus rootstocks, declares that on all kinds of soils and under different methods of irrigation it is the nature of the sweet orange seedling to form a shallow root system, and that it is a surface-growing stock which has few or no deeply penetrating roots. The sweet orange is not so hardy as either the sour or trifoliate, but trees that have been frozen back sprout readily and can be rebudded, so that it is seldom necessary to replace them. The budded sweet stock rapidly produces a shapely tree, having in this respect an advantage over the sour stock and the trifoliate, though it is surpassed by the rough lemon and the grapefruit. But for the fatal curse of mal di gomma which overshadows it, the sweet stock would probably be extensively used in S. Africa, where the sour stock fails, for Davis (18) says that there it is compatible with all varieties of orange, a vigorous grower and capable of producing fruit good enough for export within a year of budding, larger and better fruit in fact than is produced on any other stock. In Egypt again Brown (10) notes both its susceptibility to mal di gomma and the fact that trees grafted on it grow more strongly than those on sour orange. In Victoria (Aust.) the sweet orange as a stock is viewed with some approval. Cock (16), writing in 1926, describes the sweet orange as being an admirable stock with which to work, much less subject to root rot than the "common lemon" (not the rough lemon presumably) and making large trees whether worked with lemons or oranges. He considers, nevertheless, the sour stock to be superior. In New South Wales Benton (5) finds that sweet orange is satisfactory for sweet orange varieties, lemons and mandarins, but that it requires a better soil than other stocks, in default of which it will induce slower growth and the production of smaller fruits. It will maintain trees to a great age, trees 60-80 years old on this stock and on rough lemon being still in existence in Victoria. It is interesting to note that in an article by Schneider in Hadar (67) on Californian citrus growing it is stated that there is a marked tendency among growers in California to return to the sweet orange in preference to the sour stock.

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* Also called the sweet lime of Egypt, not to be confused with the Egyptian lime which is acid.

Trifoliate Orange (*Poncirus trifoliata* Raf, *Citrus trifoliata* Linn., *C. triptera.*) [See also under Yuzu.]

The trifoliate, taken as a whole, may be regarded as an erratic stock, in that its effect on the scion can never be accurately foretold. This tendency to variation Webber (96) ascribes to the existence of a number of strains having different reactions on the same scion variety, instancing the similar behaviour of the paradise apple stocks before the days of clone selection and propagation.

It has probably been used as a stock in China and Japan from very early times. It was first tried in America about 1895, and it is still extensively used as a rootstock for Satsuma orange in N. Florida (43), and in N. California (96). It also offers promise as a stock for Satsuma and for several kinds of blood orange in Sicily. Here Casella* is testing it on different types of soil, having found that it does not do well in the loose, dry soil of Acireale.

Coming, as it does, from colder regions than those which have produced the other standard stock varieties, trifoliate does not take so kindly to an existence within the tropical isotherm, so that Hume (43) does not recommend it as a stock for warm districts, suggesting that in America, for instance, it should not be grown further south than Beeville and Falfurrias, Texas, i.e., approx. lat. 27. The trifoliate orange is a deciduous tree forming a good root system with deeply penetrating roots and abundant fibre. When worked with a vigorous scion the roots increase in vigour and Hume and Webber (95) both remark that in no case has the trifoliate stock failed to outgrow the scion worked upon it ; in other words the girth of the stock at the point of union invariably becomes greater than that of its scion. In one particular the reverse has been the experience of Benton† (5), who, while confirming the phenomenon as regards oranges and mandarins, finds that trifoliate budded to lemon‡ is actually overgrown by the lemon scion. Webber considers that the overgrowth of the scion by the stock is entirely due to nutritional causes. The trifoliate is a deciduous tree bearing a comparatively sparse foliage and having a very definite winter rest period. The scions on the other hand are evergreen and are more or less continuously active. The nutrition thus afforded to the trifoliate stock by these scions is therefore in excess of its accustomed requirements and this extra supply causes it to make an abnormally rapid growth similar in its nature to sucker growth. Borings into the enlarged portions of budded trifoliate trunks revealed that the cells were larger and the wood much softer than in unbudded trifoliate trees of similar age. Hume mentions that the diameter of worked trifoliate trees just below the point of union is always greater than that of trifoliate seedlings of similar age measured at the same distance above the ground.

The soils best suited to the trifoliate orange are those of an alluvial or moisture-retaining nature, with a neutral or slightly acid reaction. It does not grow well in dry or calcareous regions. Fawcett and Lee (24) describe it as resistant to footrot and other gum diseases, somewhat susceptible to scab and very susceptible to canker. Tanaka, T. (78), in Japan, describes it as rather susceptible to canker, footrot and gummosis.

Clark Powell (60) says that in S. Africa it is subject to some undetermined disease very similar to collar rot.

It is the hardiest of all the stocks, unresponsive to sudden changes of temperature, and is reputed to convey this hardiness in some degree to the scion. Webber (96), however, does not altogether agree. He says that, whereas he has known a few cases where sweet orange varieties on trifoliate were apparently rendered slightly more hardy, it was due really to the greater dormancy imparted by the stock : he can equally recall instances where trees on trifoliate had been more severely injured by frost than those on sour orange, and in these cases the stocks themselves had been killed back to the ground. He ascribes this tenderness to scion influence. He considers that the stock is as hardy as sour orange and no more. Tanaka's (78) one objection

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* D. Casella, Director of the R. Stazione Sperimentale di Agrumicoltura e Frutticoltura, Acireale.
† R. J. Benton, Citrus Instructor, Dept. Agr., Sydney, N.S.W.
‡ Webber expressly includes lemon.

to it is that, although highly resistant to cold, it may on occasion be killed back, in which case it will not, unlike certain other citrus rootstocks, sprout again from the base and so admit of rebudding.

Trifoliate in general appears to have a dwarfing effect on the scion, though Hume considers that this theory needs qualification. He maintains that, although it has a dwarfing effect on those varieties of citrus with which it is not wholly compatible, yet with suitable scion varieties it produces trees which grow as rapidly and attain as large a size as those on sour or sweet orange stock. Davis (18) states that in South Africa it dwarfs all varieties except late oranges and tangerines. Cock (16) writing of conditions in Victoria (Aust.), describes trifoliate as being commercially a failure and as having a pronouncedly dwarfing effect on the scion. Benton (5) mentions its dwarfing tendency on lemons in N.S. Wales. Webber (97) also notes severe dwarfing in the case of lemons.

Tanaka (78) writing from Japan, a country possessing the climate and soil in which the trifoliate is most at home, where in fact it has been in use as a rootstock since the ninth century, testifies to its undoubted dwarfing effect on the trees grafted on it, but asserts that this is never accompanied by shortness of life or suppressed vigour. It maintains productivity, he considers, over a very long period and often bears abnormally large crops. As a stock for Ponkau (*Citrus poonensis* Hort. ex Tanaka) which is grown in the hot and moist, sub-tropical region of Taiwan (Formosa) it has proved very successful, maintaining its deciduous character in spite of the even climate.

Quinn (63) in South Australia considers it suitable for almost swampy and peaty lakeside land. Benton (5) in an unpublished report from N.S. Wales in 1932 says that compared with rough lemon it appears to hasten the maturity of oranges and mandarins, while a comparison of the oldest orange trees (36 years) available on trifoliate with trees of similar age on rough lemon showed the former to be more thrifty and more regularly productive. He notes, moreover, that on the few occasions when it has been used as a stock for lemons it seems to maintain a better size and condition of juice in the fruit, though the trees themselves are dwarfed and on light soils become anæmic with reduced productivity.

Davis (18) testifies to a striking improvement in quality of any fruit grown on it in South Africa. Tanaka (78) says that " as a stock for lemon it is defective, being badly attacked by footrot."

In California, Coit (17) says that trifoliate is an absolute failure for lemon trees and only uncertainly successful for orange and grapefruit. Swingle (73) finds it a useful stock for the Glen citrange, increasing the hardiness of that already hardy fruit. Brown (10) for Egypt remarks that it is totally unsuited to the conditions of the country.

The trifoliate can be raised from cuttings easily, but the more usual method is to grow it from seed. Tanaka (78) states that the variation among seedlings is very slight.

Yuzu (*C. junos* Sieb. apud Tanaka).

The Yuzu is a native of China but has been cultivated in Japanese " backyards " for many generations. It was at one time much in use as a stock, but Tanaka (78) says it has been superseded by trifoliate in commercial nurseries, though many older trees on Yuzu are to be found. The fruits are used for seasoning and are very marketable. This fact combined with the necessity for picking the fruit young makes it difficult to obtain seed in any quantity. It is a deep-rooted, long-lived plant, but as a rootstock can nevertheless be used with advantage on shallow soil which acts as a check on its propensity to induce late cropping and consequent reduction in yield.

At the Government Horticultural Station at Okitzu comparative tests between Yuzu and trifoliate stocks have been made which are here briefly summarized. Trifoliate stock contains an average of 30 polyembryonic seeds per fruit, about 3,000 to the litre. The Yuzu fruit contains 20 mono-embryonic seeds, 2,000 to the litre. Germination is good in each case, but in trifoliate it takes place two weeks sooner than in Yuzu. The growth of young trifoliate seedlings is sufficiently rapid to enable them to be worked in their second year, while with the Yuzu it is necessary to wait till the third year.

After grafting the trifoliate produces strong initial growth and early bearing, slowing down in the fourth year and finally settling into a dwarfish tree, while it is just at this time that the Yuzu begins to increase in vigour.

The fruit borne on Yuzu stock is at first larger, with a thicker, rougher skin and is more acid than that on trifoliate. As the tree ages, the appearance of the fruit changes. It is now smooth, polished and tight-skinned, but undiminished in size. There is a general belief that fruit on Yuzu stock far surpasses in quality that on trifoliate.

It is the stock on which, in Japan, Thompson Navel succeeds best. Trifoliate proving rather short lived and liable to collapse untimely, it became a practice with Japanese growers of Satsuma to graft a root of the deep-rooting long-lived Yuzu on to the Satsumas which already have a trifoliate root. The addition of this root is found to stimulate the aging Satsuma into fresh vigour and to strengthen its hold in the ground, while the combination of the two kinds of root seems to maintain the tree in excellent condition.

The Yuzu can be easily grown from stem cuttings, but in commercial propagation it is usually raised from seed.

Citrange (Hybrids between *Poncirus trifoliata and C. sinensis*).

The fruits are not much used, since they are sour and leave a bitter taste. As stocks, however, for the more palatable varieties they have considerable possibilities (73). In districts liable to cold their hardiness has proved a valuable asset. In the Satsuma rootstock trials in progress at the Agricultural Experiment Station, Florida (25), the Satsumas on Rusk citrange showed much more cold resistance than those on any other rootstock. The trees themselves are making vigorous growth and appear thoroughly congenial to this stock. It is hoped by its aid eventually to extend the cultivation of citrus into districts hitherto debarred by low temperatures from citrus cultivation.

Citrangequat (A hybrid).

This name is given to the hybrids resulting from crosses between the citrange and the kumquat, the former being itself a hybrid between the trifoliate and the sweet orange. The object of these crosses was to produce a citrus that should have a high degree of resistance to frost combined with a high degree of winter dormancy. The kumquat, besides being extremely hardy for a citrus, is able to pass through spells of hot weather which would cause other citrus varieties to break into a premature growth that would be injured by subsequent slight frosts.

Considered as a stock (76) the citrangequat has the promising features of resistance to canker and of extreme vigour. It is hardy, though less so than the citrange (73). It is compatible with Satsuma and other citrus varieties, which grow readily on it. The fact that it is a sterile hybrid means that the seeds will be of vegetative origin and will exactly reproduce the mother plant. Seeds, however, are only sparingly produced. Fortunately the citrangequat roots readily from cuttings if these are set under certain conditions, namely a bottom heat of 90° F. with a humidity maintained at 80—90° and with an air temperature lower than that of the soil, at about 70—80° F. A solar propagator can be contrived to fulfil these conditions by the aid of sun heat alone (45, 75).

Swingle and Robinson (76) call attention to the interesting fact that, while the citrangequat will root easily from cuttings, none of the three parent species used in the creation of this hybrid (sweet orange, trifoliate orange, kumquat) will root under the same conditions in America. Advantages in the use of cuttings in this case are that a full year can be saved over seedlings in growing stock to budding size and that the vigour apparent in F. 1. generations, which often diminishes in succeeding generations of self pollinated hybrid plants, can be thus perpetuated.

Rough Lemon (*Citrus Limonia* Osbeck).

Rough lemon, a horticultural variety of lemon (*C. Limonia*, Osbeck). Its origin is doubtful. Introduced into Florida, presumably from Spain, in the early days of settlement, it has now become naturalized in the forests of the southern portion of that state. In Rhodesia, where

it is also an introduction, it now grows wild along the banks of the Mazoe river, whence it takes its local name of Mazoe Lemon. To begin with a reference to a disability, it must be said that of all the commonly used stocks it is the most subject to cold. Both Hume and Webber (96) think that when used as a rootstock this sensitiveness to cold may in some way influence the scion, making it less hardy than it would otherwise be. Webber suggests that as the hardiness reputed to be transmitted to the scions on trifoliate stock is probably due to the retarding influence which trifoliate exercises on its scions, enabling them to escape the spring frosts, and not to any special cold resisting qualities conveyed to the scion, so the rough lemon may have acquired its reputation for imparting tenderness from the fact that, being a tree of rapid and early growth, it forces its scions into bud too soon to avoid winter injury.

Though not so variable as sour orange stock a number of different strains doubtless exist, each of which would eventually have its own particular effect on the scion. Among thirty seven-year-old rough lemon seedlings in one South African nursery visited, Webber separated out four markedly distinct types.

There are two varieties of rough lemon in use in the Bombay Presidency, namely Jamburi and Id. The Director of Agriculture of the Presidency in a letter on the subject of stock influence mentions that Mosambi oranges on Id stock have a thicker and more warty rind than those on Jamburi, the same effect being seen with the Santara orange, these having in addition larger fruits when worked on Id.

Rough lemon of Egypt, a variety distinct from the ordinary or Florida rough lemon, has been tried as a stock in Egypt (10). It proved to be useless, since the trees gummed badly and eventually died.

In disease resistance, unlike the common lemon, rough lemon is fairly resistant to mal di gomma and Pythiacystis gummosis, being less susceptible than the sweet orange but considerably more so than the sour. It is susceptible to scab (24, 43, 95).

An interesting observation is made by Cheema (14) who notes, in discussing the relative susceptibility of various kinds of citrus to die-back in Western India, that different varieties manifest different degrees of susceptibility, irrespective of the fact that all are worked on rough lemon.

The root system is strongly developed and well adapted for foraging in dry and sandy soils, while Davis (18) says that in South Africa it is equally at home on heavy loam.

In South Africa, the sour stock being out of the running, it is practically the only stock used. In Florida it is used on the lower east coast and the high sandy ridges of the interior. When comparison is made with the sour orange, a slight disadvantage is noted in the tendency of the trees worked on rough lemon to produce in their early years fruit of inferior quality, thick-skinned and deficient in juice, but, as Hume remarks, this is probably due to the vigorous vegetative growth of the young tree and, this phase once passed, the stock will produce as fine quality fruit as any other. Hume mentions also that fruit on rough lemon cannot be held so long on the trees as on sour stock. Oranges on it are likely to dry out at the stem end earlier (in the case of limes and lemons picked green this does not occur), and the seeds in grapefruit sprout earlier. Other influences of this stock are seen in the shape of the young trees, which have a tendency, usually corrected later, to produce a tall upright growth in the centre of the crown.

There is reputed to be an increase in acidity and a decrease in sugar in the fruit produced on this stock as compared with that on sour orange. Davis (18) in South Africa notes a slight elongation in the shape of any orange worked on it ; while Clark Powell (60), of the same country, denies any influence either in acidity or shape. In this he is supported by Webber (96), who cites experiments made at the Citrus Experiment Station, California, in which stock influence on chemical content, size, colour or time of ripening of fruit, could not be traced with sour, sweet, trifoliate and grapefruit stocks, rough lemon apparently not being tested. Webber considers that the influence of rough lemon on its scions cannot be serious. The rough lemon is also compatible as a stock with most other citrus varieties, though this does not imply that it is the best possible stock to use for them. For instance, though grapefruit does well on it, and

it is the common stock for this fruit in South Africa, Davis considers that grapefruit on its own roots will produce larger and better fruits, and size is of importance in commercial grapefruit cultivation.

In the Bombay Presidency (58) rough lemon (Jamburi) can be used as a stock for grapefruit, but the fact that the bud may take as long as six months to germinate causes the small cultivator to prefer a system of marcotting whereby the grapefruit is obtained on its own roots in about four months already 3 or 4 feet high.

Davis (18) says that used as a stock for tangerines it makes the skin coarser and imparts a a flavour of lemon to the fruit, and on the whole does not give such good results as might be expected. A successful citrus grower is quoted as declaring that he could always tell by the flavour whether a tangerine had been worked on lemon or not. Davis notes, however, that the area of tangerine growing is definitely extended by the use of rough lemon stock owing to its adaptability to soils unsuited to the sweet orange. In Florida it is used for tangerines because it increases the size of the fruit.

Its use for Satsumas cannot be recommended in Florida (43) owing to the unsatisfactory quality of the fruit thus produced. Robertson Brown (9) has also found it unsuitable for Satsumas (Sangtara) at Peshawar in India.

In Florida Bahia Navel orange (Washington Navel) is much increased in fruitfulness by the use of the rough lemon. For early oranges, such as Parson Brown, the stock is not so useful, in Florida at any rate. Here it is found that it produces inferior and late colouring fruit.

In India (9) (Peshawar) Robertson Brown's stock trials disclosed rough lemon as giving the greatest vigour and fruitfulness to the Malta orange. The fruits, he says, were large and rather coarse, perfectly globular, a rich, attractive orange colour and inclined to be thick-skinned. The juice was abundant, sparkling and somewhat acid. The seeds numerous and large.

In Egypt Brown (10) says that rough lemon has not had a sufficiently extended trial to determine its suitability, though it will probably prove useful. The Washington Navel, for instance, which fails to bear well on sour orange in that country gives promise of better results on rough lemon. Cheema (13), discussing the possibility of developing a lemon industry in Western India, advises the rough lemon as the most suitable stock.

As a stock for kumquats rough lemon is successful, but on rich soils, when the kumquat top appears to get more food material than it can deal with, Hume recommends the practice of budding the kumquat on shoots from a rough lemon root which is already carrying a sweet orange top ; even so, the kumquat will frequently outgrow the other top.

In Dominica the Agricultural Department are experimenting with the acid lime budded on rough lemon. The trees are growing well and are just coming into fruit [1932] (38).

Japanese Citron (*Citrus nobilis* Lour., hybr.).

This is the stock which figures so largely in the horticultural writings from the Dutch East Indies, under the name Japansche Citroen (53). It originated at Batoe as a seedling of a so-called sour Japanese Mandarin (*Citrus nobilis* Lour var.) and, regarded superficially, it seems to be a cross between this mandarin and *Citrus Limonia* Osbeck var. It is fairly highly polyembryonic and therefore the stocks raised from its seed do not differ from the mother tree, especially as it is possible to distinguish and eliminate the generative seedlings before the time for budding arrives (83, 86).

It is compatible in Java with all forms of orange, grapefruit and mandarin.

Shaddock (*Citrus maxima* Merril, *C. grandis* Osbeck, *C. decumana*).

The Egyptian varieties are supposed to be of value as stocks on dry land (10). The seedlings, however, which are regarded as being of hybrid origin, vary greatly, so that it is difficult to secure uniform stocks. In Egypt endeavours to do so are being made, plants approximating to the pomelo or grapefruit type being preferred. It is as immune to mal di gomma as the sour orange, but so subject to attacks of the scale (*Aspidiotus aurantii*), that the raising of young stock is often considerably hampered. Webber (96) remarks that shaddocks have been mentioned favourably as a stock for the grapefruit in South Africa, but Davis (18) says that they are unsatisfactory there.

The Cuban shaddock, considered by some to be a hybrid, has a potential value as a rootstock, since scab (*Sphaceloma Fawcettii*) which has a very stunting effect on young trees, has never been found on it (101).

In the Philippines an investigation into the influence of rootstocks on mottled leaf revealed that trees of all the commercial species of citrus were peculiarly liable to the disease when budded on shaddock, while other stocks gave much less susceptibility. Unbudded shaddocks did not develop mottled leaf and, if in a badly mottled row of budded trees a bud had failed, that stock would grow away with greater vigour and without a trace of the disease. As a rule shaddock budded on shaddock failed to contract the disease. Incompatibility between scion and stock was at first suspected, but this was considered as being disproved by the fact that, whereas mandarins budded on shaddock became mottled, shaddock budded on mandarin grew well and remained perfectly healthy (49).

Grapefruit (*C. maxima var. uvacarpa* Merril and Lee, *Citrus paradisi Macf.*).

The pomelo or grapefruit is a stock of which little but good is heard, and yet its use never seems to spread beyond certain comparatively restricted localities ; possibly because, as Hume considers, its soil adaptation is limited, or it may be that the field being already occupied by standard stocks which, between them, can cover most types of soil or climate, and against whose known idiosyncrasies the grower is forearmed, there is little inclination for him to become involved, unless driven by necessity, with a stock whose reactions are still a matter of uncertainty. At present its use on any considerable scale is mainly on the west coast region of Florida.

The root system is characterized by its fibrous nature, being better endowed in this respect than those of either the sweet or the sour orange. It has a small and crooked taproot, but the lateral roots push out to great distances (up to 26 feet in a seven-year-old tree) keeping near the soil surface but on the whole running at a lower level than those of the sweet orange (52). A heavy soil, rich in vegetable matter, seems to suit it, and under these conditions growth is rapid and vigorous. Success is also obtained on the open gravelly soils in the interior valleys of California, but on the high pine lands of Florida the hopes placed in it have not been fulfilled, since it has made slow growth and is found to be subject to " frenching " or mottled leaf, a disorder associated with the lack of humus in the soil.

Discussing the stock's susceptibility to diseases, Fawcett and Lee (24) consider it to be somewhat susceptible to mal di gomma and Pythiacystis gummosis, but they add that varieties of it exist possessing considerable resistance to these diseases. The seedlings, moreover, are not always tractable in the seed bed, often giving trouble by gumming and by blooming and setting fruit when only two or three inches high (17). Paranjpye (58) also reports from Central Provinces, India, that it suffers on having its taproot trimmed and that this feature is a disability in a stock which probably has to be transplanted several times.

Accounts of its success when worked with its own kind vary. Thus Webber (96), in his study of the citrus industry in South Africa, finds that, although the results with other varieties have not been encouraging, it has occasionally been worked with grapefruit with some success. Hume says that under suitable soil conditions it has proved successful with sweet orange and grapefruit.

In the Imperial Valley, Texas, where a grapefruit industry is developing, grapefruit as a stock for grapefruit is classed as " fairly good," though the sour orange is preferred (22).

In Hawaii (59) the grapefruit is reported to make a vigorous stock for lime, and in Dominica trial buddings with lime as a scion are vigorous and about to bear (38).

With lemons, particularly in the interior valleys of California (17), it has done well.

Yamanaikan (*C. intermedia* Hort ex Tanaka).

This rootstock which is used in the Hyuga province of Japan has the vigour and habit of the sour stock (78). Tanaka places it as botanically intermediate between grapefruit and shaddock. It is found growing semi-wild in Japan (79).

Acid Lime (*Citrus aurantifolia* Swingle).

This name embraces a number of varieties which have not been separated botanically, some being acid, some sweet. Of the acid limes the most important is the variety used in Egypt. [Sweet limes are dealt with elsewhere.—Ed.]

The Egyptian lime forms a low, spreading, thorny tree. Leaves 55—80 mm. in length and from 30—40 mm. in width ; petiole short but distinctly winged ; fruit globular or slightly oval, about 40 mm. in diameter, of an average weight of 34 grammes ; skin thin, pale yellow when ripe ; seeds usually 6 in number ; pulp pale, juicy, acid. This is the common lime of Egypt, though there are several others. Brown (10) says it makes a suitable stock for selected scions of its own kind and suggests that, owing to its resistance to drought, it might prove to be a useful stock for oranges, etc., on dry, sandy land. In trials carried out by the Horticultural Section of the Ministry of Agriculture, Egypt (21), the Egyptian lime was found to have a more favourable influence on the yield of certain sweet oranges (such as Blood and Valencia) and Mandarins (Clementine and Santara) than did three other stocks tried, namely sour orange, sweet lime and citron. It also imparts more vigour to the trees budded on it than does the sour orange. Lemons, which do badly on sour orange in Egypt, should be tried on it. It is found to be rather more difficult to work than is the sour orange. It is usually propagated from seed.

Sweet Lime (*Citrus aurantifolia* var. Swingle).

This is considered to be a variety of the acid lime, and is used largely as a stock in Palestine and India.

Turner (88) states that in spite of certain advantages of the sour orange the sweet lime is still the most popular stock in Palestine, since it is easily propagated, requires little attention, and the trees come early into bearing.

Among the old Arab growers these trees were formerly raised from cuttings, while the Jewish and German groves relied mainly on seed. The sweet lime is reputed to give quick development and to induce varieties worked on it to come into first bearing earlier, and to retain their fruit on the trees longer, while, if the trees are raised from cuttings, the fruit is of more uniform type with a finer and smoother skin. The sweet lime, however, is productive of short-lived trees, and is definitely susceptible to various forms of root and collar rots. Hodgson (40), of the University of California, as a result of his survey of the citrus industry of Palestine, weighs these advantages of the sweet lime against the disadvantages, and flatly says that in California they would scrap it and select some stock, preferably sour orange, less subject to disease. He admits that its affinity for the Shamouti or Jaffa orange is most marked, but even so he thinks that Shamouti on sour orange will eventually form bigger and certainly longer-lived trees. Moreover, he is prejudiced in favour of a slower-growing stock as being easier to control and because a strong and durable system of branches may be formed with a minimum of labour.

Mr. Samuel Lewin (51), a prominent Palestine grower, takes another view. He thinks that sweet lime has practically every advantage over sour stock including that of a better union, the sole disadvantage being its liability to gummosis. Since in Palestine this disease always attacks the tree on the west or south-west side, Mr. Lewin considers that the fierce sunlight beating on the trunk is the principal cause. That it is from this direction, too, that the cold winter winds and rains strike was pointed out, he claims, by Professor Fawcett. The fact that budding was formerly done breast high left a large area of trunk without shade. To counter these difficulties Mr. Lewin proposes that all trees should be budded on the north side, and that the trunks should be shaded for at least three years in some way, possibly by allowing suckers to grow up on the sunny side.

Robertson Brown (9) in stock trials in N.W. India, in which the production of 500 fruits by six-year-old trees in good condition may be regarded as a standard of performance, found that the sweet lime is not a suitable stock for commercially grown Maltas, though it might well be used in private gardens where a dwarf tree producing a few oranges of high quality is required. For oranges of the Santara (*Citrus nobilis* Lour) type it is perhaps the best stock available, though the branches are tall and weak and easily broken by wind or weight of fruit.

For the Central Provinces Shrivastava (69) describes sweet lime (Mitha nimbu), raised from seed as the best stock for Santara oranges, though cultivators generally use Jamburi (rough lemon.)

In Iraq (58) the sweet lime, usually raised from cuttings, is the chief stock used for the Mosambi or Portugal orange.

In Egypt stock trials (21) have indicated that the sweet lime is superior in promoting yield to the Egyptian (acid) lime, sour orange and citron as a stock for the Jaffa orange (Shamouti), Navelencia and Satsuma. In trials in which vigour of scion was taken as a criterion of congeniality the sweet lime proved the best stock for Satsuma, seedless lime and Triumph grapefruit.

Citron (*C. medica* L.).

A variety of citron is used largely as a stock in Egypt (10), though its use is not considered desirable by those who aspire to perfection in citrus culture. The fact is that it appeals to the native cultivator by the ease with which it can be propagated and worked, cuttings planted in February being ready for budding the following September without transplanting, and making saleable plants seventeen months later, or in two years from the setting of the cuttings. Budding operations are easier and more certain than with the sour orange and consequently the price is lower, while quicker initial growth, freer early bearing, and somewhat larger fruit are undoubted advantages in the eyes of those unthinking growers whose ambitions are satisfied with a quick return for their outlay, even at the eventual cost of an orchard of trees, short-lived and diseased, dying at the very time when they should be most productive. Endeavours are made to prolong the life of the trees by planting them with the union below ground in the hope that they will thus throw out roots from the scion.

That trees grafted on citron are very inferior in vigour and resistance to disease is now definitely established by the investigations of the Horticultural Section of the Egyptian Ministry of Agriculture (10, 21). They fail to respond to heavy cutting back for the purposes of renovation, and the only justification for the continued use of the stock is in cases where a cheap, temporary plantation is needed between other trees.

Fawcett and Lee (24) describe the citron as being the most susceptible to frost of all citrus varieties, though Coit (17) says it is less so than lime. It is susceptible to gum diseases.

Mandarin Orange (*C. nobilis* var. *deliciosa* Swingle).

The mandarin is used as a stock almost exclusively in the Swatow region in China, where it is found to give very satisfactory results (49).

The Cleopatra Mandarin (90) is a stock used occasionally in Florida. It is immune to scab, resistant to gummosis and as hardy as the sour stock. It requires a well drained, sandy soil and will not endure a low wet situation.

Cleopatra stocks which have been budded should be transplanted within a year or losses may occur ; the transplanting should only be done when the trees are thoroughly dormant. It is compatible with tangerines, satsumas and kumquats. Trees on Cleopatra mandarin tend to form denser heads than those on sweet orange or rough lemon (66).

Sunki (*C. Sunki* Hort.).

The Sunki is allied to the Cleopatra orange of America. The rootstock effect is semi-dwarfing and it is not long-lived. It is a loose-skinned orange with inferior fruit. As a stock it is mainly used in Taiwan, Formosa, and on the opposite Chinese coast (78, 81).

Tangerine (*C. nobilis* var. *deliciosa* Swingle).

The Tangerine is used as a stock for its own kind in South Africa with satisfactory results. The most suitable soil for it is a deep, rich, well-drained loam (19).

Citrus hystrix D.C.*

Has been tried as a stock in Dominica (20). The trees developed with extraordinary vigour but were eventually killed by footrot, and the trial has been abandoned. The pointed leaved form is often severely attacked by scab, while the round leaved variety has never been known to suffer (101).

* See also *Papeda* among Other *Rutaceae*.

STOCK.	DISTRIBUTION.	SOIL ADAPTABILITY AND ROOTS.	STOCK EFFECT.
Sour Orange: *Citrus Aurantium.*	Throughout citrus growing regions except S. Africa.	Clay subsoils, wet or heavy soils. Roots are abundant and deeply penetrating. Withstands irrigation conditions well.	Not free bearing in ea years but fruit of go quality from start. La bears freely. Accentua tendency to biennial beari in Egypt. Dwarfing effe in Egypt; ditto on lig land in S. Australia.
Sweet Orange. *Citrus sinensis.*	Universal but not generally used owing to disease susceptibility.	Light, dry soils owing to susceptibility to mal di gomma. Root system shallow, the main mass in horizontal layer about 18″ thick, starting at 10″ below soil surface.	Rapidly produces a shape tree, being superior in t respect to sour orange a trifoliate, though not rough lemon and grapefru
Trifoliate. *Citrus trifoliata.*	Japan, China, N. Florida. N. California, in colder districts.	Alluvial or moisture retaining soils with neutral or slightly acid reaction. Roots are deeply penetrating with abundant fibre.	The stock outgrows t scion in circumferen Often somewhat dwarfi though this is possibly d to slight incompatibility a environmental conditio In New South Wales appears to give quic maturity than rough lem and more regular product on rich soils. Impro quality of fruit.
Rough Lemon. *Citrus Limonia.*	Practically universal.	Especially suitable for sandy soils, but adaptable over a wide range.	Fruits in the early years liable to be of infer quality, due to vigor vegetative growth; later produces as fine fruit as a other stock. Trees on have tendency, correct later, to tall upright grow in centre of crown. Florida considered to crease the size of tangerin Evidence contradictory to influence on taste a shape of fruit. Increa fruitfulness of Bahia Na orange in Florida.
Grapefruit. *Citrus maxima* var. *uvacarpa.*	West coast region of Florida commercially. In all countries experimentally.	Heavy soil rich in humus; also on certain open gravelly soils, as interior valleys in California. Root system has small and crooked tap root with long laterals, running at a lower level than in case of sweet orange.	
Sweet Lime. *Citrus aurantifolia.* var.	Palestine. India. Iraq.		Quick development a early first bearing. Sh life.

INCOMPATIBILITY.	DISEASE.	
	Resistant to	*Susceptible to*
Satsuma,* kumquat, lime,† limequat. Oranges in S. Africa. Egyptian sweet lemon or lime and some seedless lemons in Egypt. Malta orange, in N.W. India.‡ Lemon trees in California often show decline after 10 years, possibly due to stock. *Compatible in N.W. India. †Compatible in Brit. W. Indies. ‡Compatible in U.S.A.	Mal di gomma. Pythiacystis gummosis, and most of the other gum diseases. Psorosis and decorticosis.	Scab (highly).* Citrus canker. Citrus blast (slightly). *Does not convey susceptibility to scions.
	Scab. Bark disease of the Orient. Decorticosis.	Mal di gomma. Pythiacystis gummosis. Psorosis, leprosis or nail head rust. Melanose. Citrus blast (highly). Citrus canker (moderately).
Gives poor results with lemon.	Frost injury. Mal di gomma. Pythiacystis gummosis and other gum diseases.	Citrus canker (highly). Scab (moderately).
	N.B.—This stock is practically the only stock compatible everywhere with Satsuma orange.	
Satsuma. In Florida with early oranges produces inferior and late-colouring fruit.	Fairly, to mal di gomma and Pythiacystis gummosis. Subject to certain forms of gum disease and therefore unsuitable for lemons in California.	Scab.
Still largely a matter of experiment.	Certain strains possess more resistance than others to Pythiacystis gummosis and mal di gomma.	Mal di gomma and Pythiacystis gummosis (slightly). Gumming of seedlings in seed bed.
Unsuitable for Malta orange, if grown on commercial scale.		Pythiacystis gummosis and various forms of gum disease.

2. Other *Rutaceae* worth consideration.

Among other *Rutaceae* worth investigation as to their potentialities as stocks* for citrus, either directly or after hybridization [*see* Swingle (2), Cheema (14), Ochse (53), Goossens (28), Benton (5), Winston (101)] are the following :—

Aegle Marmelos, Correa. Bael Fruit. This stock has been tried by Cheema in N.W. India with results not stated.

Aeglopsis Chevalieri, Swingle. A native of the Ivory Coast, West Africa. It forms a small, spiny tree with ovate leaves, flowers 4—40, small, in branched panicles. The fruits are globose or pyriform, deep orange with a hard thin shell $\frac{1}{16}$ in. thick, containing 6 cells filled with large, sub-lenticular seeds embedded in a fragrant mucilage. It inhabits swampy land near the sea and may thus prove to be of value as a stock on which to graft citrus on alkaline land. Trees are now growing at the Jardin des Plantes, Paris, and in the greenhouses of the United States Department of Agriculture. In America seedlings are being tested as stocks.

Atalantia spp. Small trees or shrubs of which twelve or fifteen species are known, the range extending from India through Malaya to Australia. The following have possibilities as rootstocks.

A. monophylla, D.C. Type of the genus, India and Ceylon. One of the most promising species both for rootstock and breeding purposes.

A. macrophylla, Kurz. Andaman Islands, Burma, Malaya. Swingle considers this tree, which has attained a height of 40 ft. in Java, to be of exceptional interest for trial as a rootstock, and for breeding work. It bears larger fruits ($1\frac{1}{2}$—2 inches in diameter) and reaches a greater height than any other species of *Atalantia*.

A. citrioides, Pierre. A small, usually spiny tree from Indo-China. It can be grafted with success on grapefruit and is now being tested as a rootstock in U.S.A.

A. ceylonica, Oliver. Native of India and Ceylon, where it forms a much branched, spiny, small tree. Its large seeds render it likely to produce vigorous seedlings. Owing to the dryness of the fruits Swingle considers it more likely to be of use as a stock than for breeding work.

A. Guillauminii, Swingle. Has large fruits and seeds, and should produce vigorous seedlings.

A. simplicifolia, Engl. Is spineless with unusually large leaves. [Varieties with strongly marked characteristics in the leaves are sought after by hybridists, who are utilizing the phenomenon of polyembryony in stock work.—Ed.]

Balsamocitrus spp. Three species are known, all from Tropical Africa.

B. Dawei, Stapf. A large tree, 50—60 ft. in height, occurring in forest east of Lake Nyanza and in Uganda at an altitude of 2,000—3,000 ft. Swingle says that this seems to be a promising stock on which to graft the bael fruit, *Aegle Marmelos*, which is difficult to grow on its own roots. *B. Dawei* is an extremely local variety and Swingle (74) says that as far as he knows the only plants in cultivation are those at Washington and at the Riverside Experiment Station, California. Grown from seed collected by the discoverer, M. T. Dawe, now Director of Agriculture in Cyprus, it has not yet fruited in cultivation nor will it propagate from cuttings or marcottes, in fact all attempts to propagate it on its own roots were unsuccessful until the application of the nurse-grafted Y cutting method, described elsewhere in this paper.

B. paniculata, Swingle. Commonly planted in the villages of Nigeria and the Gold Coast.

B. gabonensis, Swingle. Native of North French Congo and South Cameroons. May prove of value as a stock for citrus on account of its vigour and healthiness.

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* Nearly all are being tested as stocks by the U.S. Dept. Agriculture, Washington, D.C.

Chaetospermum glutinosa, Swingle. TABOG. The only species is a native of Luzon, Philippine Islands. It develops a vigorous rootgrowth. Experimental buddings of oranges, lemons, grapefruits and kumquats on this stock show considerable promise.

Chalcas exotica, Millsp. (*Murraea exotica* L.) ORANGE JESSAMINE. Under greenhouse conditions this plant makes a remarkably vigorous rootgrowth ; lemons budded on it grow rapidly. It should be tested in a situation where a vigorous root system is required.

Citropsis spp. AFRICAN CHERRY ORANGES. These are considered by Swingle to be worth a trial as stocks. He seems, however, more impressed with their possibilities in hybridizing, since they have sweet, strongly flavoured fruit and unusually large compound leaves. They themselves grow readily on all the stocks commonly used for citrus. The various species are described in *J. Agr. Res.*, Vol. I, pp. 419-436.

Glaucena Lansium, Skeels. WAMPI. Native of S. China, where it is cultivated for its fruits. It is grown in Hawaii to some extent, It can be grafted on to grapefruit and other citrus.

Eremocitrus glauca, Swingle. AUSTRALIAN DESERT KUMQUAT. Native of sub-tropical parts of Queensland, and New South Wales. This citrus supports successfully conditions of extreme drought and comparatively severe cold. It will, in fact, endure cold better than any other member of the citrus family, besides being the only one exhibiting marked drought-resisting adaptations. The emarginate leaves are small, 1—1½ x ⅛ x ¼ inches, possessing palisade cells on both faces, with the stomata at the bottom of deep pits. The slender spines are born in the axils of the leaves, which they exceed in length. The small flattened or pyriform fruits have an acid taste and are used for jam, pickling, and in the preparation of cooling drinks. Both for breeding purposes and as a stock it is being tested in the southern and western states of America. Two hybrid crosses with this plant are showing considerable promise. In Australia (5) the Department of Agriculture, New South Wales, have been experimenting with this species as a stock, but attempts to work young seedlings by the usual method of budding or grafting have so far met with no success. The seedlings are of very slow growth, at any rate in the locality in which the experiments have been made, and it takes 5 or 6 years for them to attain a suitable size. It is interesting to note that they make most headway in periods of drought, which are, however, rare at the Departmental Nursery. Cuttings under glass, with and without bottom heat, have failed to grow.

Feroniella lucida, Swingle. KAVISTA-BATU. A small, evergreen, spiny tree with compound leaves of six to twelve leaflets, fruits globose, about 2¼ inches in diameter, growing wild in the drier parts of Java, has been tried as a stock in Java, without much success according to Ochse (53), the buds soon dying. It has also been introduced into the U.S. for testing as a stock.

Feronia Elephantum, Correa. WOOD APPLE. This has been tested as a stock from time to time. Cheema (14) states that in the Bombay Presidency he has grafted by approach 40 two-year-old *Feronia* stocks with Santra and Mosambi (loose and tight-skinned) oranges, and that every one succeeded, the union taking place in about 50 days. Growth is vigorous. Propagated at present by seed. Swingle mentions that *Feronia*, as a stock plant, is being tested by the U.S. Dept. Agr. in Washington, D.C., and California.

Glycosmis spp. Small spineless trees or shrubs found in India, Ceylon, Australia, Philippines and China.

Hesperethusa crenulata, Roem (*Limonia crenulata*, Roxbg.). NAIBEL. A spiny shrub, with light green compound leaves of five to nine leaflets, and bearing small, bitter (not sour), dark-coloured fruits, ⅓—½ inch in diameter. Native of dry hills in Ceylon, India, Burma and Indo-China. The root system is vigorous. It grows well when grafted on grapefruit, lemon and tabog (*Chaetospermum glutinosa*), and could probably be used as a stock for these and other citrus varieties.

Limonia Poggei, Engl. var *latialata*, de Wild. (28) A native of Equatorial Africa, it has given promise of success as a stock in the Belgian Congo, its immunity to the attacks of a longicorn beetle (*Monohammus* sp.), which had destroyed great numbers of citrus trees of many different varieties, chiefly by boring extensive galleries in the cambium round the base of the trunk, leading to its trial. It has proved to be compatible with sweet orange, mandarin, grapefruit and lemon, tending to impart a more vigorous growth to the scion than does the sour orange.

In its wild state it is fairly frequent in Equatorial Africa, where it forms a tree 24—30 feet high. The bark is smooth and greyish. Leaves imparipinnate with two pairs of leaflets, the petiole and rachis winged, the stipules modified into spines 2—3 cm. in length. Flowers white, with a strong perfume of orange blossom. The fruits resemble small oranges, 2—2·5 cm. in diameter, ripening a clear lemon yellow. The pulp is resinous and scented and contains 3 to 4 large seeds.

Merope angulata, Swingle. KIGERUKKAN. The only species known inhabits the tidal swamps of Java. It is a small spiny tree bearing curious angular fruits. Its salt resistant properties make it worth a trial as a stock.

Microcitrus, spp. Small spiny trees or shrubs from Australia having dimorphic leaves.

M. australasica, Swingle. (*Citrus australasica*, Muell). FINGER-LIME. This species flowers and fruits at an early age, and is particularly hardy, and so promising for breeding purposes. It can be propagated from cuttings. [These two last factors suggest its possibilities as a stock.—ED.]

M. australis, Swingle. (*Citrus australis*, Planch). DOOJA. A round-fruited lime from coastal forests of Queensland. It grows to a considerable size (60 ft.) and bears large fruits up to 3 inches in diameter. Swingle remarks that in California it shows considerable resistance to cold.

Micromelum spp. Small spineless trees or shrubs from Indo-China, India and Malaya.

Pamburus missionis, Swingle. A small tree of India and Ceylon, occurring in sandy soil near the sea coast. As a stock it is worth a trial.

Papeda spp. Probably a subgenus of citrus and closely allied if not identical with *Citrus hystrix* (101). A number of forms are found in Indo-Malaya and Polynesia, but it is doubtful if they are valid species. A distinguishing feature of the group is the very large, broadly-winged petiole which sometimes exceeds the area of the lamina. They are used to some extent as stocks for other citrus varieties in the Philippines.

Paramignya monophylla, Wight. Is an evergreen climbing shrub, native of India, which is being tested as a stock by U.S. Department of Agriculture.

Pleiospermium spp.

Two varieties, *P. alatum*, Swingle, TUMPAT-KURUNDU, from dry regions in India and Ceylon, and *P. dubium*, Swingle, KIDJEROEKAN, from Java are known.

Both, Swingle thinks, are worth testing as stocks. The seeds do not long remain viable, which renders their importation into distant countries a matter of difficulty. Both are small trees.

Severinia buxifolia, Ten. A spiny, dwarf tree from S. China, often used as a hedge plant in the Gulf States. It will endure ground too salt to support commercial citrus and is therefore being tested for stock purposes in U.S.A. It can be propagated without difficulty from cuttings.

Triphasia trifolia, P. Wilson. LIME BERRY. An ornamental shrub or small tree fairly widely grown in the tropics. It will grow on land which is too salt for the commercial citrus varieties and for this reason it is being tested in stock trials by the U.S. Dept. of Agriculture. It is somewhat susceptible to frost.

3. Identification of Stocks.

Among older plantations, especially where different types of stock have been used, a considerable mixture of stocks is evident. Such plantations offer, therefore, excellent material for studying stock-scion compatibility, provided it is possible to identify the stocks in question.

Occasionally identification is possible from sprouts arising from below the bud union and in some cases the type of bud union suggests the stock.

Lately efforts have been made to identify stocks by colorimetric tests. Work has been done in America by Hendrickson (39) and by Halma and Haas (34), and is actually in progress at the sub-tropical Horticultural Research Station at Nelspruit, Eastern Transvaal (1).

Hendrickson's method is based on the fact that all citrus roots contain varying amounts of glucosides and that these contain phenols. On treating an aqueous extract of ground, fresh roots with ferric chloride he observed different shades of colour with the sour orange, wild grapefruit and rough lemon, while the colour produced in the case of sweet orange varied. Actually he considers the method reliable for rough lemon alone.

Greater success has been gained by Halma and Haas with powered bark, their most consistent results arising from the Almen test. The reagent is prepared as follows :—Saturate fuming nitric acid with mercury and dilute the solution with double its volume of water. The procedure recommended is as follows :—Peal off enough clean bark to make at least 1 gram when dried at 70°C. Grind fine enough to pass through a 40 mesh sieve. Place the resulting powder in a beaker, together with 20 cc. distilled water. Filter through filter paper and wash residue twice with 20 cc. water. Measure 10 cc. of the filtrate into a test tube and add 8 drops of reagent. A heavy, yellowish precipitate will form at once. Boil for a few minutes in a water bath or open flame. Within a short time the heavy precipitate and the solution become coloured. Let the solution cool and the precipitate settle. Frequent shaking seems to accentuate the colour of the solution on settling.

With sweet orange the solution assumes a characteristic pink colour which persists for several weeks. The grapefruit solution is a much lighter pink and the colour fades much sooner. Sour orange usually develops a light pink colour and quite often this is difficult to distinguish from that given by grapefruit. The rough lemon gives the lightest colour of all and, with a little experience, no special difficulties are encountered in its determination.

A modification giving greater colour differences in a shorter time is as follows :—10 cc. of the filtrate are made alkali with a few drops of potassium hydroxide and then 8 drops of a saturated solution of copper sulphate are added. A heavy precipitate forms. Eight drops of the mercury reagent are then added and the contents of the tube are boiled. The colour of the sweet orange solution becomes pink, that of the sour orange brown, and easily distinguishable from it ; the grapefruit solution becomes light pink and that of the rough lemon remains nearly colourless. Halma gives a list of supplemental tests, which he considers helpful but not so reliable as the above.

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